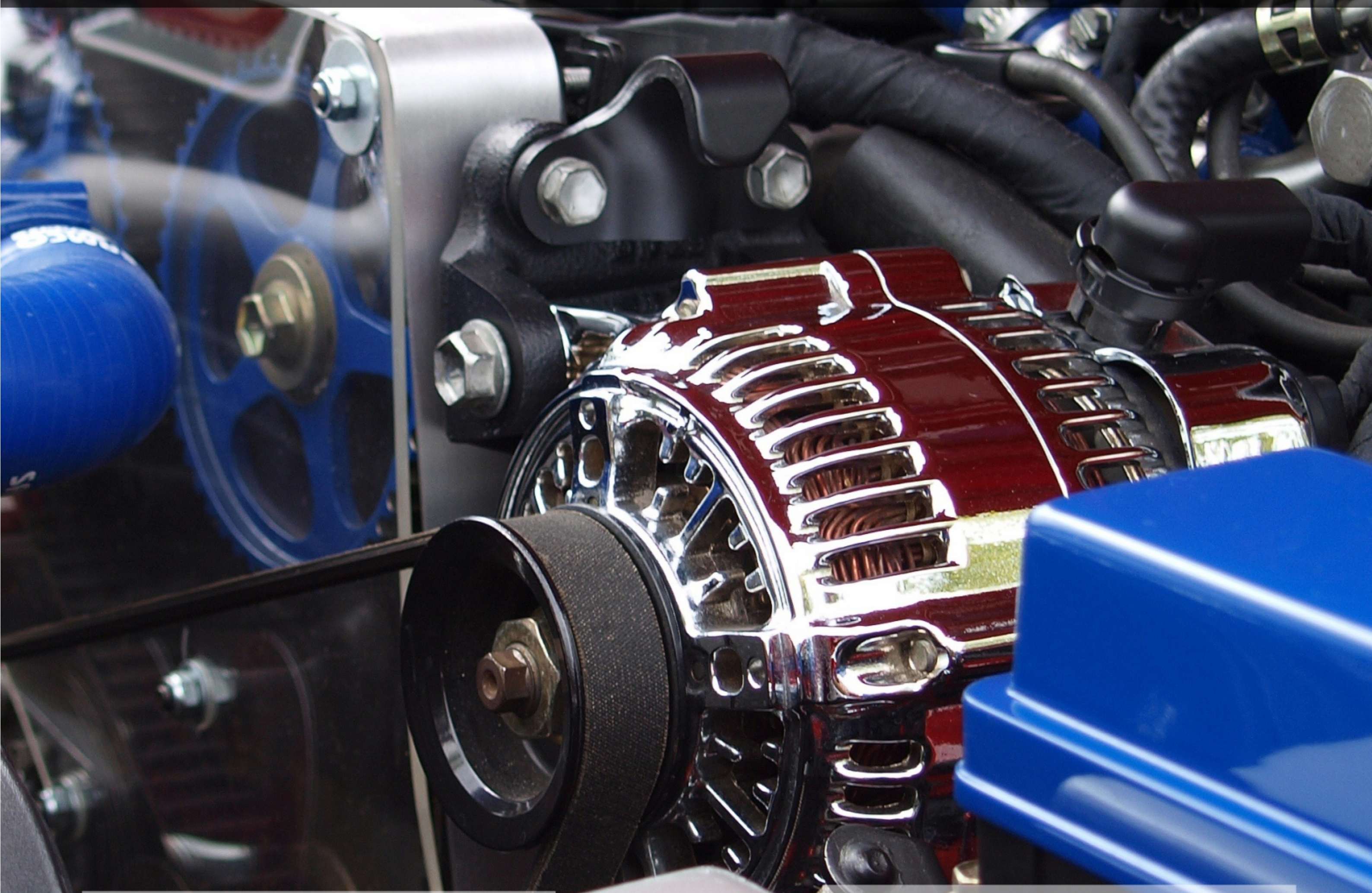
Online ISSN : 2249-4596
Print ISSN : 0975-5861
DOI : 10.17406/GJRE

Global Journal of Researches in Engineering: A

Mechanical & Mechanics Engineering



Induction-Heating Method

Parameter Over a Range of Speeds

Highlights

Development of Local Diameter

Processing Method by High-Frequency

Discovering Thoughts, Inventing Future

VOLUME 18 ISSUE 2 VERSION 1.0

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering

Volume 18 Issue 2 (Ver. 1.0)

Open Association of Research Society

Incorporation No.: 0423089
License No.: 42125/022010/1186
Registration No.: 430374
Import-Export Code: 1109007027
Employer Identification Number (EIN):
USA Tax ID: 98-0673427

Global Journals Inc.

*(A Delaware USA Incorporation with "Good Standing"; **Reg. Number: 0423089**)*

Sponsors: *Open Association of Research Society*
Open Scientific Standards

Publisher's Headquarters office

Global Journals® Headquarters
945th Concord Streets,
Framingham Massachusetts Pin: 01701,
United States of America
USA Toll Free: +001-888-839-7392
USA Toll Free Fax: +001-888-839-7392

Offset Typesetting

Global Journals Incorporated
2nd, Lansdowne, Lansdowne Rd., Croydon-Surrey,
Pin: CR9 2ER, United Kingdom

Packaging & Continental Dispatching

Global Journals Pvt Ltd
E-3130 Sudama Nagar, Near Gopur Square,
Indore, M.P., Pin:452009, India

Find a correspondence nodal officer near you

To find nodal officer of your country, please email us at *local@globaljournals.org*

eContacts

Press Inquiries: *press@globaljournals.org*
Investor Inquiries: *investors@globaljournals.org*
Technical Support: *technology@globaljournals.org*
Media & Releases: *media@globaljournals.org*

Pricing (Excluding Air Parcel Charges):

Yearly Subscription (Personal & Institutional)
250 USD (B/W) & 350 USD (Color)

Editorial Board

Global Journal of Research in Engineering

Contents of the Issue

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 18 Issue 2 Version 1.0 Year 2018
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN:2249-4596 Print ISSN:0975-5861

Domestic Microwave Oven and Fixed Geometry Waveguide Applicator Processing of Organic Compounds and Biomaterials: A Review

By Victor J. Law & Denis P. Dowling
University College Dublin

Abstract- This paper reviews the use of domestic microwave ovens and fixed geometry waveguide applicators for processing of organic compounds and biomaterials. The review traces the microwave (fo ~ 2.45 GHz) technological development of proof-of-principle and batch processes highlighting their advantages and disadvantages. Amongst the rapid homogeneous and heterogeneous processes reported are the treatment of organic compounds, thawing fresh frozen blood plasma, microwave-assisted desolvation, microwave-assisted extraction of bioactive materials, cleaning of dentures, plasma cleaning of polymer surfaces and plasma deposition of carbon-nanostructures. The arc-like plasmoid generated when foodstuff such as grapes are treated in a microwave oven is explored along with a study of microwave irradiated cherry tomatoes.

Keywords: *microwave oven, waveguide, organic compounds, biomaterials, arc-like plasmoids, plasma.*

GJRE-A Classification: *FOR Code: 091399p*

DOMESTICMICROWAVEOVENANDFIXEDGEOMETRYWAVEGUIDEAPPLICATORPROCESSINGOFORGANICCOMPOUNDSANDBIOMATERIALSAREVIEW

Strictly as per the compliance and regulations of:

Domestic Microwave Oven and Fixed Geometry Waveguide Applicator Processing of Organic Compounds and Biomaterials: A Review

Victor J. Law [α] & Denis P. Dowling [σ]

Abstract- This paper reviews the use of domestic microwave ovens and fixed geometry waveguide applicators for processing of organic compounds and biomaterials. The review traces the microwave ($f_o \sim 2.45$ GHz) technological development of proof-of-principle and batch processes highlighting their advantages and disadvantages. Amongst the rapid homogeneous and heterogeneous processes reported are the treatment of organic compounds, thawing fresh frozen blood plasma, microwave-assisted desolvation, microwave-assisted extraction of bioactive materials, cleaning of dentures, plasma cleaning of polymer surfaces and plasma deposition of carbon-nanostructures. The arc-like plasmoid generated when foodstuff such as grapes are treated in a microwave oven is explored along with a study of microwave irradiated cherry tomatoes.

Keywords: microwave oven, waveguide, organic compounds, biomaterials, arc-like plasmoids, plasma.

I. Introduction

The introduction of the tabletop domestic microwave oven into homes and restaurants has enabled food to be defrosted and cooked more rapidly compared with conventional techniques. The convenience and low cost of ownership of the oven has lead to many other uses that include dielectric heating and plasma processing of inorganic and organic materials including biomaterials. The most common feature in the oven is the multimode resonant cavity (MRC) that is illuminated through one side wall of the cavity using a rectangular transverse electric (TE_{10}) waveguide with an interior waveguide aspect ratio of 2:1. This houses a packaged cavity-magnetron operating at a frequency of $f_o = 2.45 \pm 0.1$ GHz ($\lambda_o \sim 12.2$ cm). Using this configuration limited auto-impedance matching between the magnetron and the loaded MRC is achieved with no other impedance matching apparatus required. A refinement (or sub-category) of this design is the mono-mode fixed geometry waveguide applicator.

The aim of this paper is to review the use of multi-mode microwave ovens and mono-mode cavity applicators in the processing of organic compounds and biomaterials. The review includes the microwave oven production of plasmoids (fireballs) from fruit. It is important to note that microwave processing of food on an industry scale is outside the scope of this review. A recent comprehensive review of this area (including some of the equations used here) can be found in [1].

This work reports on a number of different microwave system designs, therefore in order to facilitate and ease the comparison between devices and processes the original device and power levels are given. In the case where plasma is used the gas pressure is stated and converted to the equivalent SI unit of pressure (Pascal). As both the biological component of blood (plasma) and electrical discharge (plasma) are discussed, the word plasma referring to biological material is written in italics' and in plain text (plasma) when referring electrical gas discharge.

In the case of organic compounds it is well known that the reaction rates are generally proportional to the polarity of molecules containing bonds between atoms with very different electronegativities, such as oxygen and hydrogen [2]. Non polar compounds such as carbon tetrachloride and hydrocarbon solvents do not absorb significant amounts of microwave energy. Whereas the polarity of biomaterials is more complex in that the induced electromagnetic field varies with their constituents parts. To quantify molecule polarity it therefore becomes necessary to use the materials dielectric properties. In this work four properties are considered and are listed as follows.

First, the materials dielectric constant (ε') which is a dimensionless number and is a measure of a materials ability to couple with microwave energy. The relationship of ε' to the effective wavelength within a material at a given frequency is given in equation 1.

$$\lambda' = \frac{c}{f_o\sqrt{\varepsilon'}} \qquad (1)$$

In this equation, c is the speed of light (3×10^8 $m.s^{-1}$) and f_o is the magnetron frequency (2.45×10^9 Hz). From this relationship it becomes apparent that non-uniform heating of materials due to their size and geometry is an issue and one that is highlighted numerous times in this work.

The dielectric loss factor (ε'') is the second dimensionless number that is used as a measure of the materials ability to be heated by absorb microwave

Author α σ: School of Mechanical and Materials Engineering, University College Dublin, Belfield, Dublin 4, D04 V1W8, Ireland.
e-mail: viclaw66@gmail.com

energy (via direct current or ohmic heating) and turned into heat. The ratio of ε"/ε' is called the loss tangent or dissipation factor and describes how easily the material is penetrated by the microwaves.

Thirdly, the penetration depth (d_p) is a measure of how deep microwaves can penetrate into the material that is being irradiated. It is defined as the depth where the dissipated power is reduced to e^{-1} (approximately 37%) of the initial power entering the surface. One formulation of this definition is given in equation 2.

$$d_p = \frac{\lambda_0 \sqrt{\epsilon'}}{2\pi\epsilon''} \quad (2)$$

From an electric engineering point of view the penetration depth equates to one skin depth (δ) in a metal layer, or electrical plasma, where three skin depths (three fold of e^{-1}) would be used to describe the full microwave radiation penetration [3]. However since the focus of this paper is organic compounds and biomaterials one skin depth [penetration depth] is sufficient. This is because when biological materials undergo ohmic heating its electrical conductivity increases due to ionic mobility as structural changes occurs in the tissue like cell wall protopectin breakdown, expulsion of non conductive gas bubbles and lowering in aqueous phase viscosity: all of which lead to an enhanced concentration of electrolytes, especially at high voltage gradients.

The thermal power (P) measured in units of Watts ($J.s^{-1}$) dissipated in the material may be estimated using the calorimetric equation 3 [4].

$$P = mC_p \frac{\Delta T}{t} \quad (3)$$

Where m is the density of the material ($kg.m^{-3}$), C_p is the specific heat capacity of the material ($J.Kg^{-1}K^{-1}$), ΔT is the change in material temperature (final temperature - initial temperature, t is the heating time (s).

To obtain the electric field strength (E, measured in units of $V.m^{-1}$), in which the process has taken place the power measurement is divided by the materials volume (V) thereby accessing E via the ohmic heating equation (4).

$$\frac{P}{V} = 2\pi f_o \epsilon_0 \varepsilon'' E^2 \quad (4)$$

In this equation the $2\pi f_o \varepsilon_o \varepsilon''$ term represents the dielectric conductivity (σ) of the material, where (ε_o) is the permittivity of free space (8.8542 x 10^{-12} $F.m^{-1}$).

The remaining part of this review paper is structured as follows: Section 2 looks at microwave irradiation of organic compounds and biomaterials (thawing of frozen blood plasma components and disinfection and sterilisation of surfaces). Section 3 looks at microwave plasma processing of organic compounds in the presence of a passive catalyst (aerial-antenna igniter). Section 4 looks at microwave experiments in school and at home in particular the production of arc-like plasmoids from cherry tomatoes and grapes. The dielectric heating mechanisms that underpin these processes are developed here. Finally Section 5 provides the conclusion to this review paper.

II. Microwave Irradiation of Organic Compounds and Biomaterials

a) *Early processing of organic compounds*

The origins of dielectric heating of food can be traced back to demonstrations of food cooking at 1933 Chicago World's Fair [5] and the first microwave cooking of foodstuff patent application filed in 1945 [6]. This was followed by the first commercial microwave cooker built and sold by Raytheon in 1947 and Amana in 1967 [5, 7]. These ovens where of limited commercial success due to their bulk and cost, but success came later when the cost effective packaged cavity-magnetron became available [8, 9]. Although combination of microwave heating and chemical reactions were reported in early 1980s, it was not until large scale microwave oven production became available, that rapid synthesis of organic compounds became available. The work by Gedye et al [10, 11] provides an early standard for proof-of-principle synthesis of organic compounds within a microwave oven. In their work they used a domestic Toshiba ER-800 BTC set to a power level of 180 to 560 W with a process time between 1 and 5 minutes. The organic reactions were carried out in replaceable 120 and 300 ml Teflon reactions vessels, where the reactants comprised 10% by volume of the vessel. Using this microwave method they showed that many polar compounds that require up to 2.5 hours to prepare using the thermal heating method can be synthesized effectively in a few minutes without significantly altering the reaction pathway. A schematic of the microwave oven used for these organic reactions is shown 1A. The safety procedures relating to the 'microwave superheating effect' in the absence of any stirring [2] of organic liquid products (solvents) [10, 11] are restated here:

1. For processes that used more than 560 W and longer than 5 minutes: PFA reactions vessels fitted with pressure a pressure relief value designed to vent at approximately 100 psi (690 kappa) should be used.
2. After the heating is completed, the vessel is left to stand in the oven for 2 min to reduce the pressure in the vessel. Then the hot vessel is removed from the oven and cooled in ice-water for a further 5 min before the top being unscrewed.
3. When processing flammable organic solvents the microwave oven should be placed in a fume hood or within a fume cupboard.

Global Journal of Researches in Engineering (A) Volume XVIII Issue II Version I Year 2018

b) Microwave thawing of fresh frozen plasma

Since the microwave (1.7 to 24 GHz) measurements on human blood by Cook in the early 1950s [12, 13] it is well known that the blood dielectric constant exhibits an inverse frequency dependence. Within this dependence there are at least two flat (relaxation) regions: β-dispersion arising from the polarization of the cell membranes in the 10 KHz-to-200MHz region and the γ-dispersion region (near 18 GHz) due to the reorientation of water molecules [14]. A challenge to the thawing of blood products is the starting temperature as it takes much longer to melt ice, than to heat H_2O in the liquid phase by 1°C: this is because the molecules are held in a crystal lattice that prevent the dipoles from following the microwave fields as they can in the liquid water phase.

In 1984 Luff et al, reported on the operation of 2.45 GHz microwave oven for the rapid thawing of fresh frozen plasma (FFP) with conventional water bath thawing at 37°C [15]. In their work they highlight the need for short duty cycle irradiation times (typically a 225 ml FFP bag required a duty cycle of 10 seconds on, 5 seconds off for a process of time of 8-10 minutes) and to understand the effect of dielectric heating on the various blood components and the appearance of flocculent regions within the blood bags that are associated with the ovens multi-mode field hot-spots.

The water environment microwave thawing technique was reported by Mead et al 1996 [16]. In this work a Sharp Carousel II Model R5850 oven is used, in which the FFP is totally immersed in an uncovered bowl containing 1.5 l of tepid tap water. A schematic of this is shown in figure 1B. Their studies revealed a considerably reduction in flocculent regions in both size and amount which they attributed to a more even heat distribution within the frozen plasma.

By 1992, Churchill et al [17] was using a specifically designed microwave oven (We slabs Plasma Defroster) for thawing up to 4 x 200 ml FFP bags at a time. To test the new oven design they used coagulation screen tests and levels of coagulation proteins in both microwave and water bath thawed samples. Their results revealed little clinical difference between the two techniques, although the microwave irradiation procedure gave shorter turnaround times (of the order of 7 minutes per bag) compared to the water bath discrepancies increases when multiple bags of plasma are needed which is a major factor of consideration when thawing in emergency treatment of trauma victims.

c) Microwave desolvation systems

In the mid 1990s the microwave oven desolvation system based on microwave aerosol heating was developed for inductively couple plasma mass spectrometry [18]. The system used the Balay Model W-2235, domestic microwave oven with a normal pulsed 900 W power. With the turntable removed a single-pass spray chamber (80 cm^3) made of Pyrex glass is centrally positioned in the MRC with the end plate of the chamber fixed to the internal rear wall so allowing the outside mounted nebulizer to be connected to the spray chamber. A water dummy-load was also placed within the MRC to prevent damage to the magnetron. See figure 1C.

The desolvation system was developed into a microwave TM_{010}-mode cavity by Grind lay et al in 2005 [19] and further developed in 2009 [20]. In these systems a cylindrical metal cavity forming a single coherent mono-mode microwave field is used and within which the spray chamber is positioned. The microwave cavity is then illuminated through an iris in the longitudinal side of the cavity. In this configuration a greatly reduced power level of 300 W was found to produce similar aerosol effects as compared to [18]. A schematic of the TM_{010}-mode cavity and waveguide is shown in figure 1D.

d) Microwave-assisted extraction of bioactive material

The first US Patent for microwave-assisted extraction (MAE) of natural products from biological material was filed in 1990 and published in 1991 [21]. The patent was followed by a series of publications by Lagha et al [22] and Clemat et al [23]. Their work provides studies of digestion and the extraction of terpenes from caraway seeds with n-hexane as the solvent in a TE_{10} mode waveguide applicator, rather than using a microwave oven. This applicator involved the use of magnetron power levels in the range 10 to 120 W, with a processing times up to 60 minutes, see figure 1E.

In contrast to [22, 23], Li et al [24] gives little information on the microwave-assisted extraction device they used for the extraction of natural antioxidants from the exotic gordonia axillaris. It is worth noting that Ledesma-Escobar et al [25] and Medina-Torres et al [26] have performed comparative studies of ultrasonic-assisted extraction (UAE) for bioactive products with other extraction methods including MAE. In their work they highlight that UAE provides a less aggressive environment to that of MAE and note that the important factor of bioactivity of the targeted products should be considered rather than the extraction rate.

e) Microwave disinfection of dentures

In 2012 Brondani, et al published a critical review on the subject of microwave denture cleaning [27]. In their work they highlighted that power levels above 850 W and irradiation times longer than 15 minutes produced denture distortion: in addition based on the known phenomena that DNA molecules still present in dead bacteria can be transferred to live bacteria [28] and that microwave irradiation kills microorganisms, but does not remove them from the surface. Thus 'microwave' irradiation has only a momentary disinfection effect. The review was shortly followed by Sesma *et al* looked at the effectiveness of

Global Journal of Researches in Engineering (A) Volume XVIII Issue II Version I Year 2018

denture cleaning associated with and without microwave disinfection, with and without dentures brushing [29]. They found that microwave irradiation in combination with soaking in denture cleanser and brushing is more effective in removing the bio film when compared to the use of microwave irradiation only: thus revealing the absence of mass transportation mechanisms at the denture surface when using only microwave irradiation. They also noted that some authors have suggested the use of denture microwave steam cleaning to improve disinfection efficiency: this is because bubbles released by the boiling water help in removing microorganisms from the surface.

f) Microwave sterilisation of glass and plastic

Microwave sterilisation of glassware preserving jars and plastic food containers has become commonplace in homes [30]. In general the process comprises the use of pre-washed containers filled with tap water and placed in a microwave oven and irradiated for 2 to 3 minutes. Indeed there are many commercial steam cleaning products sold for use in microwave ovens. In the case of microwave induced steam cleaning of suitable microwave plastic dishware leaching, or migration, of aromatic and chlorinated hydrocarbons is a health concern. Torrison has reported on a brief gas chromatograph/mass spectrometer study on three different types of plastic dishware containing water that were irradiated within a microwave oven for 10 minutes [31]. The result of this study however was inconclusive and no information on the microwave oven power settings were given.

More recently (2014) Dhawan et el used Fourier transform infrared spectrometry to investigate microwave induced silicon migration through high-barrier coated multilayer polymeric films after microwave processing [32]. The study was carried out using selected food simulating liquids (FSLs, which represent aqueous and low-acid foods) [32]. In their study the microwave system (Discover SP-D CEM MW system (CEM Corporation, Matthews, NC, USA) contained a single-mode cavity with a 35 ml quartz test cell with a maximum working volume of 25 ml. Three time-temperature combinations (pre-heating, processing and cooling) stages were selected to match closely with the commercial sterilization and pasteurization schedules for single meal-sized pouches containing low-acid foods [33]. In the microwave process range of 70 to 123 °C) and 18 to 34 minutes, their study indicated that silicon may migrate from high gas barrier commercial multilayer coated films into the FSLs. No significant difference was found however in the level of silicon migration after microwave irradiation when compared with conventional heated water bath (121°C) processes.

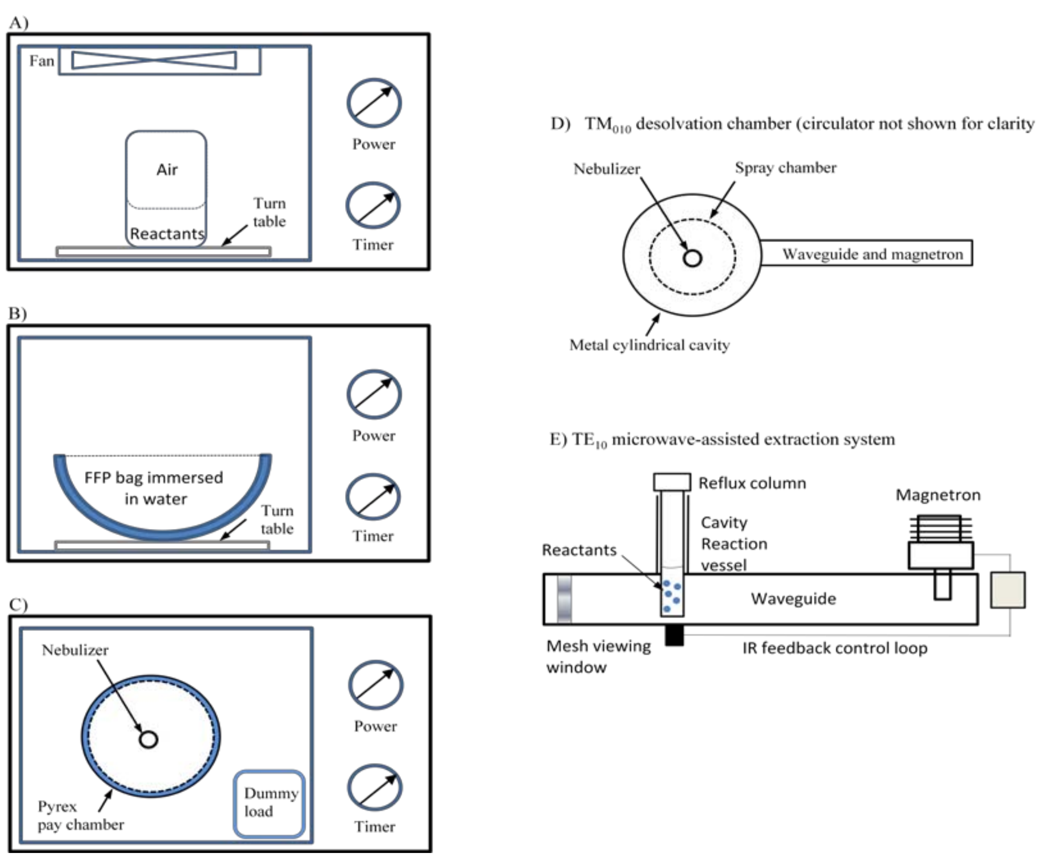


Figure 1: Front view schematic of non-plasma microwave cavity systems described in this paper.

III. Microwave Plasma Processing of Organic Compounds

When sufficient electromagnetic energy (i.e. provided by the microwaves) is applied to neutral gas, the plasma can be formed in a converted microwave oven [34]. A review of the oven conversion process, calibration and reactions obtained was published in 2018 [4]. Five of the heterogeneous organic reactions reported in [4] are given here.

In 2003 Ginn and Steinbock presented their plasma cleaning of poly (dimethylsiloxane) (PDMS) surfaces using modified microwave oven (Amana, ACM2160AB) [35]. In their oven the turntable was replaced with an evacuated (~10^{-3} Torr (0.133 Pascal)) desiccator in which the samples was removed and the desiccator chamber in which the samples were placed along with an aerial antenna. Using the maximum power (1100W,) the plasma was generated using the residual gas. Finally pre and post evaluation of the cleaning process was performed using the surface water contact angles method. Their results revealed that a dramatic change in PDMS surface contact angle from 112 ±2°C to less than 15° for plasma exposure times of more than 25 seconds. This hydrophobic to hydrophilic prosperity change has been widely reported to be associated with enhanced levels of oxygen functionality of the polymer surface after plasma treatment [36]. This work was followed by a number of YouTube postings showing microwave oven plasma cleaning of glass slides, see for example [37].

Khongkrapan et al reported on the pyrolysis of paper to produce gaseous waste by-products. This was carried out using a converted commercial microwave oven with a continuous power of 800 W for 3 to 4 minutes [38, 39]. In their oven the process occurs inside a cylindrical quartz tube (internal/external diameters of 27/30 mm and length of 250 mm) that coaxially passes vertical through the MRC. After a pre-vacuum stage, air or argon is used as the precursor gas at a nominal atmospheric pressure (101 k Pascal) with the gas flowing from the bottom to the top of the MRC. The shredded paper (5 g) is suspended in the centre of the tube. A front view schematic of their converted oven is shown in figure 3A. They also used a aerial-antenna igniter to start the plasma, for further details of the igniter see [4].

Nomura et al [40, 41] and Toyta et al [42] have described the use of a converted microwave oven for plasma in-liquid decomposition of n-dodecane (molecular formula: $C_{12}H_{26}$ (l)) to simultaneously produce hydrogen gas and carbide in the hydrocarbon liquid using a microwave output power of 500 to 750 W. A typical representation of these reactors is shown in figure 2A. The reaction is performed in a closed volume Pyrex reaction vessel containing 500 ml of n-dodecane liquid with one or more igniters]. Also, two silicon/PTFE tubes are inserted from the top of the cavity, one tube used for the carrying gas (argon) as the precursor gas and the second tube used to collect both the spent argon and by-product gas at a working pressure close to atmospheric pressure.

In 2010 Singh and Jarvis reported the generation of carbon-nanostructures within a continuously pumped 3-port reaction flask (made from borosilicate glass and 1000 ml volume) that was held within the 1000 W rated microwave oven [43]. To support the vessel and facilitate access to it the oven door was replaced with an aluminium plate of the same size that has three apertures; one for each flask port. With the flask supported, the flask was evacuated from the outside of the oven: using one port while the other two ports provide carrier gas (hydrogen) and the selected hydrocarbon precursor based on their hydrogen-to-carbon ratio (ethanol (C_2H_6O), xylene (C_8H_{10}) or toluene (C_7H_8)). To enhance the reaction a 2 mm diameter aerial-antenna igniter was mounted on a stainless-steel base within the reaction flask. As no vacuum pressure or microwave power was reported it is assumed that the flask was sub atmospheric and the microwave power was at maximum (1000 W). Their converted microwave oven results revealed that selectively between onion-like nanostructures and carbon nanotubes can be achieved. For the production of carbon nanotubes an ethanol (C_2H_5OH) solution with the heterocyclic compound thiophene (C_4H_4S) as an additive plus a number of aerial-antenna igniters. For growth of onion-like nanostructures, either toluene ((CH_3) C6H4) or xylene ($(CH_3)_2C_6H_4$) is used without an aerial-antenna igniter. It is worth noting that in the latter case the prior plasma art used a high cost unbalanced magnetron sputtering system [44].

In the same publication year (2018) of reference [4] plasma induced synthesis of carbon nano-materials from waste rice husk powered using a Samsung microwave oven (M539 MAN200405W) operating at 600 W for 38 minutes was reported by Anaswi et al [45]. Their experiments revealed that the vacuum pressure 1 mbar (100 Pascal) played a critical role in the deposition process. The incorporation of the organ metallic compound ferrocene (Fe $(C_5H_5)_2$) was also found to have a catalytic role in the plasma induced reaction. They also concluded that the use of waste biomass (rice husks) could be used as a source for high-value carbon nanostructures. They speculated that this may help to solve the environmental issue caused by the world's huge production of waste biomass. The converted oven has a similar coaxial narrow tube configuration as used by Khongkrapan et al [38, 39]. A generic front view schematic of these converted microwave ovens is shown in figure 2B.

Global Journal of Researches in Engineering (A) Volume XVIII Issue II Version I Year 2018

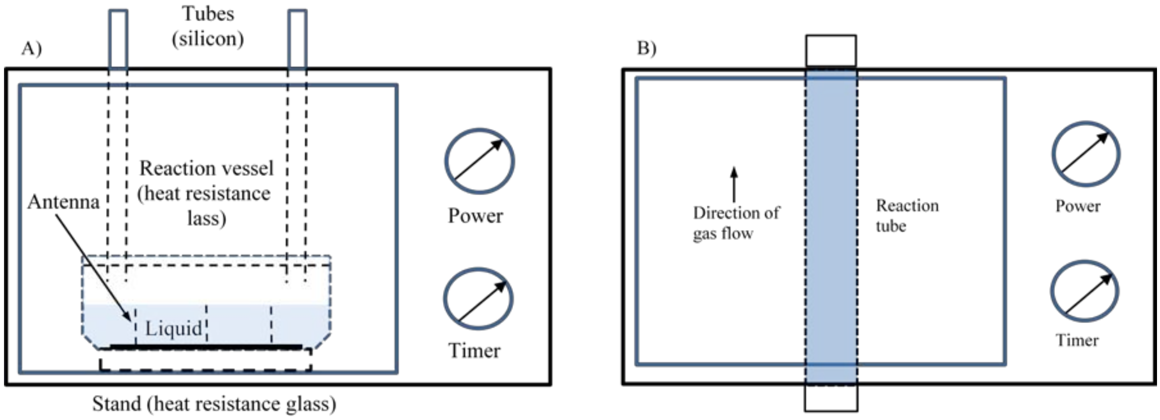


Figure 2: Front view schematic of the converted microwave ovens for plasma processing described in this paper. For clarity the auxiliary gas lines outside the ovens are not shown.

IV. Microwave Oven Experiments in School and at Home

Stanley et al [46] have reviewed the use of microwave oven experiments as a teaching resource within schools. The experiments ranged from: the: generation of plasma balls, exploding eggs and the creation of soap sculptures.

The production of plasmoids at home in a microwave oven is also a common topic for YouTube postings. Perhaps the simplest way of producing a plasmoid without modification to the microwave oven is to place a partially sliced grape (that has its two halves connected via a thin piece of skin) on the centre of the microwave oven glass turntable and then turn-on the microwave power for a maximum time of 8 to 10 seconds. YouTube reference [47] shows that arc-like plasmoids are generated at the skin bridge that connects the two grape halves; with the discharge emission continuing until the skin bridge has burnt through and the two halves are separated. This type of reaction is not limited to slices grapes as it also happens when two whole grapes are placed together in the microwave oven and when the microwave power is turned-on the generation of arc-like plasma repeatedly forces the two grapes apart leading to a recoil reaction that finishes when the volumetric heating deforms the grape shape so they do not fall onto each other [48].

The authors have repeated the YouTube postings using fresh raw sliced 2 cm diameter (spherical volume of the order of 4.2 x10^{-6} m^3) red and yellow cherry tomatoes within a microwave oven (Blue sky BMG20-8, rated output power of 800 W) for 8 seconds at a applied power setting of 55% (440 W) which equates to 3.52 KJ of energy delivered to the MRC. Figure 3A shows a freshly sliced red cherry tomato along with its constituent parts (placental, seeds and paricarp). In this case the partially sliced cherry tomatoes form a arc-like plasma until the skin bridge is burnt through (typically at 80 to 90°C, some 60 to 70°C above room temperature). See figure 3B. Once this point is reached the arc-like plasma stops leaving two separated tomato halves, both of which will continue to undergo volumetric heating until the microwave power is turned-off.

To understand the mechanisms behind the cherry tomato reactions their dielectric properties (ε', ε" and d_p) are evoked. Table 1 lists For the red cherry tomato, these properties have been determined using an open-ended coaxial probe [49]. the mean bulk properties of cherry tomatoes at 2.45 GHz over a given specific temperature range.

Global Journal of Researches in Engineering (A) Volume XVIII Issue II Version I Year 2018

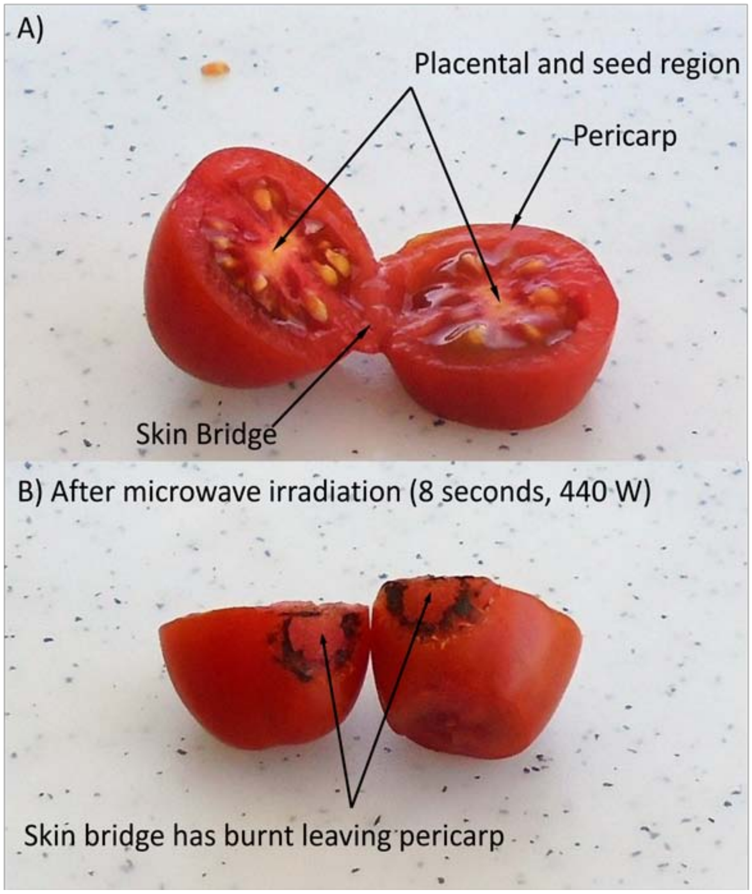


Figure 3: The appearance of a sliced red cherry tomato before microwave irradiation (A) and after microwave irradiated for 8 seconds, 440 W (B).

First consider the effect of cherry tomatoes mean dielectric constant (ε' = 67 at 2.45 GHz) in the temperature range of 20 and 120°C. Using this value in equation 1, an effective wavelength of value of $\lambda' \sim 15$ mm is obtained which fits well into the cross-sectional dimension of each tomato half. The close match between physical dimensions (20 mm diameter) of the tomato and it effective wavelength at 2.45 GHz indicates that cherry tomatoes have strong ability to absorb the microwave energy.

Table 1: Mean bulk dielectric properties of fresh raw red cherry tomato at 2.45GHz.

Fruit (temperature range)	ε'	ε''	λ' (mm)	d_p (mm)*	Reference
Cherry tomato (20 to 120°C)	67 ±10	12.5 ± 3.5	14.9 ±1	13 ±3.5	49

*Calculated using equation 2.

Table 2: Specific heat capacity of materials used in the calculations.

Material	C_p (J/ (g.K)	Reference
Water	4.184	4
Tomato paste	3.981	50
Tomato juice	3.719	51
Mean C_p	3.961 ±0.223	
Grape juice	3.395	52

Now considered the tomato's dielectric lost factor (ε'') and the narrow skin bridge which turns the two halves of the tomato in to a dipole where free electrons are pushed back and forth through the narrow bridge. Under these conditions electric current (I) flowing through the resistance (R) of the skin bridge can produce arc-like plasmoid that rapidly burns through to leave two separated tomato halves leaving the paricarp visually undamaged, see figure 3B. During this process volumetric dielectric heating rapidly increases temperature of the fruit leading to material vaporization that generates a cloud of electrons and ions which in turn feeds the arc-like plasmoid.

The microwave computed bulk penetration depth (derived from the constituent dielectric properties of tomatoes Peng et al [49]) is calculated using equation 2 and the results listed in Table 1; column 5. Here it can be seen that the computed bulk d_p value of 13 ±3.5 mm is lists the computed fits well within the radii of the tomato, and allowing for another two-fold in e^{-1} depth it is reasonable to assume that full dielectric heating of the cherry tomato is achieved.

Given that fresh raw red cherry tomatoes have a minimum water content of 90% [50] the thermal power transferred from the microwave irradiation to the tomatoes can be estimated using calorimetric equation 3: where the C_p value is computed from the mean value of water (C_p = 4.184 J/g.K [4]), tomato paste (C_p = 3.981 J/g.K [50]) and tomato juice (C_p = 3.719 J/g·K [51]) which equate to 3.961 ±0.223. See table 2. Given this approach the power transferred to the tomato equates to 208 ±14 W, or 47% of the applied power (440 W) from the microwave oven magnetron.

With the knowledge of the transferred power being 208 ±14 W, the electric field strength (V.cm^{-1}) in which these process occurs may now be estimated using the ohmic heating equation 4; which yields a value of 54 ±1.7 V.cm^{-1}. It is worth noting that the computed value is in the range (40-70V.m^{-1}) studied by Srivastav and Roy [51] for fresh tomato juice. In their study they found the juice electrical conductivity is strongly dependent on temperature as well as the influence of the ohmic heating process within the fruit.

It is also noted that similar microwave irradiation experiments on sliced yellow tomatoes produced similar arc-like plasmoids indicting that the reduced levels of chlorophyll and enhanced levels of yellow carotenoids has little effect on the production of the arc-like plasmoid.

It is now worth comparing the microwave irradiated grapes experiments posted on YouTube [46, 47] with Thomson seedless grape dielectric properties published by Tulasidas et al [52]. This is performed by computing the mean bulk dielectric properties as for the cherry tomato within a temperature of 20 to 90°C. The results of these computations are shown in table 3.

Table 3: Dielectric properties of fresh raw grape at 2.45 GHz.

Fruit (temperature range)	ε'	ε''	λ' (mm)	d_p (mm)*
Grapes (20 to 90°C)	66 ±10	13 ±5	14.9 ±1	13.7 ±4

*Calculated using equation 2.

A comparison of the data within Table 1 and 3 reveals there is little difference in dielectric properties between tomatoes products and grape. When taking into account Bingol et al calculations of the specific heat capacity of grapes (table 2) [52] it may be concluded that the grape and cherry tomato have similar dimensional and dielectric properties and therefore similar ohmic heating and arc-like behaviour when irradiated in a microwave oven. These results also support the observation that both fruits exhibit an inherent active plasma catalytic property [4, 54] within them role in the production of arc-like plasmoids.

V. Conclusions

This work has reviewed the domestic microwave oven and the microwave fixed geometry waveguide applicator for proof-of-principle and small scale batch processing of organic compounds, biomaterials and carbon nano-materials. Where possible the microwave device has been stated along with the microwave power conditions. In all cases the power source is the package cavity-magnetron. In some cases the delivered power to the MRC is not available. For surface sterilisation process the estimated surface temperature is reported. Given this, it is reasonable to assume most of the microwave power conditions are below 800 W, which is lower than the general rule for inorganic material processing within a microwave oven.

The papers reviewed in this work highlight that the extraction of bioactive compounds and disinfection/sterilisation of thermal sensitive polymers require low temperatures and therefore the requirement for low deliverable power (less than 120 W). In addition a means of mass transport from the irradiated surface is required for effective disinfection/sterilisation.

Sub-atmospheric to nominal atmospheric pressure (101 k Pascal) microwave plasma processing of carbon nanostructures has been described. In these processes a passive plasma catalyst is used which comprise a single, or multiple, aerial-antenna igniter that have a physical length approximating to ¼ or ½ of the microwave length in which they are immersed in. By selecting the hydrogen-to-carbon ratio within the organic precursor compound product selectivity between carbon nanotubes and onion-like nanostructures that have the potential to be used as encapsulated drug delivery systems can be achieved; where the external layer provides protection to the drug within.

In the home kitchen, arc-like plasmoid production from a sliced grape along with (to the author's knowledge the first report) sliced cherry tomato has been discussed. The mechanism of arc-like plasmoid production from both fruits has been discussed in terms of dielectric constant, dielectric loss and penetration depth. The process occurs at absorbed power of 208 ±14 W within an electric field of 54 ±1.7 V.cm^{-1}. The analysis supports the suggestion that slice grape and cherry tomatoes exhibits a dipole like behaviour and that the fruit can act as an active plasma catalyst as the fruit electrolyte can supply free electrons to the reaction.

Acknowledgments

The authors would like to acknowledge the support of SFI through the I-Form Advanced Manufacturing Research Center 16/RC/3872. The Authors declare that there is no conflict of interest regarding the publication of this paper.

References Références Referencias

1. O. I. Joseph. Microwave heating in food processing. BAOJ Nutrition. 13(1), pp9, 2017.
2. L. Perreux and A. Loupy. A tentative rationalization of microwave effects in organic synthesis according to reaction medium and mechanism considerations. Tetrahedron 57, 9199-9223, 2001.
3. V. J. Law. Microwave near-field plasma probe. Vacuum. 51(3), 463-468, 1998.
4. V. J. Law and D. P. Dowling. Converting a Microwave oven into a plasma reactor: a review. International Journal of Chemical Engineering. 2018, 12pp, 2018.
5. A. Davis. A history of the microwave oven. The IEEE News Source. https://www.theinstitute.ieee.org/tech-history/technology-history/a-history-of-the-microwave-oven.
6. P. L. Spencer. Method of treating foodstuffs. US. 2,495,429. (Issued Jan 24, 1950).
7. J. M. Osepchuk. The history of the microwave oven: A critical review. Digest IEEE Int. Microwave Symposium, 1397-1400, 2009.
8. J. R. Mims. US. 3,739,225. Microwave magnetron. (Issued June 12, 1973).
9. T. Koinuma. US. 3,809,590. Magnetron. (Issued May 7, 1974).
10. R. N. Gedye, F. Smith and K. C. West away. The rapid synthesis of organic compounds in microwave ovens. Can. J. Chem. 6(1), 17-26, 1988.
11. R. N. Gedye, W. Rank and K. C. West away. The rapid synthesis of organic compounds in microwave ovens. II. Can. J. Chem. 69(4), 706-711, 1991.
12. H. F. Cook. Dielectric behaviour of human blood at microwave frequencies. Nature. 168, 247-248, 1951.
13. H. F. Cook. A comparison of the dielectric behaviour of pure water and human blood at microwave frequencies. Br. J. Appl. Phys. 3(8), 249-255, 1952.
14. M. Wolf, R. Gulich, P. Lunkenheimer and A. Loidl. Broadband dielectric spectroscopy on human blood. Biochim. Biophys. Acta. 1810(8), 727-740, 2011.
15. R. D. Luff, C. M. Kessler and W. R. Bell. Microwave technology for the rapid thawing of frozen blood components Am. J. Clin. Pahol. 83, 59-64, 1985.
16. J. H. Mead, B. P. Boucock, R. E. Russell, C. S. Robinson and G. Harris. Water environment microwave thawing. A.J.C.P. 85(4), 510-513, 1986.
17. W. H. Churchill, B. Schmidt, J. Lindsey, M. Greenberg, S. Boudrow and C. Brugnara. Thawing fresh frozen plasma in a microwave oven a comparison with thawing in a 37 °C water bath. Transfusion Medicine. 97(2), 227-232. 1992.
18. Mora, A. Canals, V. Hernandis, E. H. van Veen and M. T. C. de Loos-Vollebregt. Evaluation of a microwave desolvation system in inductively coupled plasma mass spectrometry with low acid concentration solutions. J Anal. At. Spectrom. 13, 175-181, 1983.
19. G. Grindlay, S. Maestre, J. Mora, V. Hernandis and L. Gras. A microwave assisted desolvation system based on the use of a TM010 cavity for inductively coupled plasma based analytical techniques. J. Anal. At. Spectrom. 20. 455-461, 2005.
20. G. Grindlay, L. Gras, J. Montiel, V Hernandis and J. Mora. Design and evaluation of a new fully microwave-assisted liquid sample introduction device for inductively coupled plasma atomic emission spectrometry. J. Anal. At. Spectrom. 5. 519-515, 2010.
21. J. R. Pare, M. Sigomin, J. Lapointe, Microwave-assisted natural products extraction. US. 5,002,784. (Issued Mar 26, 1991).
22. A. Lagha, S. Chemat, P. V. Bartels and F. Chemat. Microwave-ultrasound combined reactor suitable for atmospheric sample preparation procedure of biological and chemical products. Analusis. 27, 452-457, 1999.
23. S. Chemat, H. Ait-Amar, A. Lagha, D. C. Esveld. Microwave-assisted kinetics of terpenes from caraway seeds. Chem. Eng. Proc. 44 1320–1326, 2005.
24. Y. Li, S. Li, Sheng-Jun Lin, Jiao-Jiao Zhang, Cai-Ning Zhao 1 and Hua-Bin Li. Microwave-Assisted extraction of natural antioxidants from the exotic gordonia axillaris Fruit: optimization and identification of phenolic compounds. Molecules. 22, 1481 16pp, 2017.
25. C. A. Ledsema-Escobar, F. E Capote, M. D. Luque de Castro. Comparative study of the effect of sample pretreatment and extraction on the determination of flavonoids from lemon (citrus limon). PloS one. 11, 1, 2016.
26. N. Medina-Torres, T. Ayora-Talavera, H. Espinosa-Andrews, Angeles Sánchez-Contreras and N. Pacheco. Ultrasound assisted extraction for the recovery of phenolic compounds from vegetable sources. Agronomy. 7(47), 2017.
27. M. A. Brondani, F. Samim and H, Feng. A conventional microwave oven for denture cleaning: a critical review. Gerodontology. 29, 6-15, 2012.

28. N. Sesma, A. L. Rocha1, D. C. Laganá, B. Costa and S. Morimoto. Effectiveness of denture cleanser associated with microwave disinfection and brushing of complete dentures: in vivo study. Brazilian Dental Journal. 24(4), 357-36, 2013.
29. O. T. Avery, C. M. MacLeod, M. McCarty. Studies on the chemical nature of the substance inducing transformation of pneumococcal types. J. Exp. Medicine. 79, 137-158, 1944.
30. M. J Renfrew, M. Mc Loughlin and A. McFadden. Cleaning and sterilisation of infant feeding equipment: a systematic review. Public Health Nutrition. 11(11), 1188-1199, 2008.
31. L. Torrison. The effect of microwave radiation on polypropylene used in food containers. Cantaurus. 7, 44-46, May 1999.
32. S. Dhawan, S. S. Sablani, J. Tang, G. V. Barbosa-Cànovas, J. L. Ullman and K. Bhunia. Silicon migration from high-barrier coated multilayer polymeric films to selected food simulants after microwave processing treatments. Packag. Technol. Sci. 27, 625–638, 2014.
33. Z. Tang, G. Mikhaylenko, F. Liu, J. H. Mah, J. Tang, R. Pandit, F. Younce. Microwave sterilization of sliced beef in gravy in 7 oz trays. J. Food Engineering. 89, 375-383. 2008.
34. A. Ribner. Microwave plasma etching machine and method of etching. US 4,804,431 (issued Feb 14, 1989).
35. B. T. Ginn and O. Steinbock. Polymer surface modification using microwave-oven-generated plasma. Langmuir.19, 8117-8118, 2003.
36. Plasma processing for tailoring the surface properties of polymers, H. Abourayana and D. P. Dowling, book chapter in Surface Energy, Intech-Open Access Publisher, edited by M. Aliofkhazraei, ISBN 978-953-51-2216-6, 123-152, 2015.A.
37. Tallaire. Plasma cleaning in modified microwave oven at LSPM (CNRS): https:/ / www. You tube. com/watch?v=e0k4G_HhceQ
38. P. Khongkrapan, N. Tippayawong and T. Kiatsiriroat. Thermochemical conversion of waste papers to fuel gas in a microwave plasma reactor. J. Clean Energy Technologies. 1(2), 80-83, 2013.
39. P. Khongkrapan, P. Thanompongchart, N. Tippayawong and T. Kiatsiriroat. Fuel gas and char from pyrolysis of waste paper in a microwave plasma reactor. IJEE. 4(6), 969-974, 2013.
40. S. Nomura, H. Toyota, S. Mukasa H. Yamashita, T. Maehara and A. Kawashima. Production of hydrogen in a conventional microwave oven. J. Appl. Phys. 106(7), 073306, 2009.
41. S. Nomura, H. Yamashita, H. Toyota, S. Mukasa and Y. Okamura. Simultaneous production of hydrogen and carbon nanotubes in a conventional microwave Oven. International Symposium on Plasma Chemistry (ISPC19). Bochum, Germany. 65, 2009.
42. H. Toyota, S. Nomura and S. Mukasa. A practical electrode for microwave plasma processes. International Journal of Materials Science and Applications. 2(3), 83-88, 2013.
43. R. Singh and A. L. L. Jarvis. Microwave plasma-enhanced chemical vapour deposition growth of carbon nanostructures. S. Afr. J. Sci. 106(5-6), 4 pp, 2010.
44. E. Iwamura and T Kinoshita. Oinon-like nanostructures film and its production. US. 6,559,492, B2. (Issued July 29, 2003).
45. M. Asnawi, S. Azhari, M. N. Hamidon, I. Ismail and I. Helina. Synthesis of carbon nonmaterial's from rice husk via microwave oven. J. Nan materials. 2018, 4 pp, 2018.
46. H. Stanley. Microwave experiments at school. Science in School, 12(summer), 31-33, 2009.
47. Soxfreak5243. Grapes making fireballs in the micro-wave:https://www.youtube.com/watch?v=JrD6yzem DRw.
48. A. Slepkov. Slow-motion grapes and hydrogel beads making plasma in microwave oven: https://www.youtube.com/watch?v=0LmaXQsssYY.
49. J. Peng, J. Tang, Y. Jiao, S. G. Bohnet, D. M. Barrett. Dielectric properties of tomatoes assisting in the development of microwave pasteurization and sterilization processes. LWT - Food Science and Technology. 54, 367-376, 2003.
50. H. Darvishi, A. Hosainpou, and F. Nargesi. Ohmic heating behaviour and electrical conductivity of tomato paste. Journal of Nutrition & Food Sciences. 2(9), 1000167 2012.
51. S. Srivastav and S. Roy. Changes in electrical conductivity of liquid foods during Ohmic heating. Int J Agric & Biol Eng. 7(5), 133-138, 2014.
52. T. N. Tulasidas, G. S. V. Raghavan, F. van de Voort and R Girard. Dielectric properties of grapes and sugar solutions at 2.45 GHz. The Journal of Microwave Power and Electromagnetic Energy: a publication of the International Microwave Power Institute. 117-123, 1995.
53. G. Bingol, Z. Pan, J. S. Roberts, Y. O. Devres and M. O. Balaban. Mathematical modeling of microwave-assisted convective heating and drying of grapes. Int J Agric & Biol Eng. 1(2), 46-54, 2008.
54. D. Kumar, S. Kumar. Plasma assisted joining. US. 7,309,843 B2. (Issued Dec 17, 2007): https:// www.youtube.com/channel/UCfG3h7mSltjtsKcXH0d FCHQ.

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 18 Issue 2 Version 1.0 Year 2018
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN:2249-4596 Print ISSN:0975-5861

Development of Local Diameter-Enlarged Processing Method by High-Frequency Induction-Heating Method

By Xia Zhu, Keiji Ogi & Nagatoshi Okabe
Ehime University

Abstract- In the present work, a new local hot working method is proposed to achieve a higher diameter-enlargement ratio and higher processing efficiency than those that can be obtained by cold working. Further, a high-frequency induction-heating device is built; this device is installed in a diameter-enlargement processing machine developed originally. A local diameter-enlargement part was formed by processing after being heated locally by the heating device, and its diameter-enlargement deformation behavior and its surface temperature were investigated experimentally. The diameter-enlargement ratio achieved with the proposed method was twice the diameter-enlargement ratio that can be achieved by cold working, with local heating for 120 s. This hot working method was effective for the diameter-enlargement forming process. The diameter-enlargement deformation behavior can be predicted approximately by a cycle parameter considering the effect of blue shortness.

Keywords: diameter-enlargement ratio, heating time, surface temperature, local hot working, blue shortness.

GJRE-A Classification: FOR Code: 091399

DEVELOPMENTOFLOCALDIAMETERENLARGEDPROCESSINGMETHODBYHIGHFREQUENCYINDUCTIONHEATINGMETHOD

Development of Local Diameter-Enlarged Processing Method by High-Frequency Induction-Heating Method

Xia Zhu [α], Keiji Ogi [σ] & Nagatoshi Okabe [ρ]

Abstract- In the present work, a new local hot working method is proposed to achieve a higher diameter-enlargement ratio and higher processing efficiency than those that can be obtained by cold working. Further, a high-frequency induction-heating device is built; this device is installed in a diameter-enlargement processing machine developed originally. A local diameter-enlargement part was formed by processing after being heated locally by the heating device, and its diameter-enlargement deformation behavior and its surface temperature were investigated experimentally. The diameter-enlargement ratio achieved with the proposed method was twice the diameter-enlargement ratio that can be achieved by cold working, with local heating for 120 s. This hot working method was effective for the diameter-enlargement forming process. The diameter-enlargement deformation behavior can be predicted approximately by a cycle parameter considering the effect of blue shortness.

Keywords: diameter-enlargement ratio, heating time, surface temperature, local hot working, blue shortness.

I. Introduction

Shafts having a larger local diameter than themselves are required in many mechanical parts, such as bearing stops and gear locations. A part with a large local diameter is called a "diameter-enlargement part." Usually, cutting work or welding a fat ring on the shaft is used to work the part. However, these processing methods arise about the uselessness of the material for cutting work or the decrease of strength in the welded area. Thus, a new cold working method is proposed to enlarge the local diameter of a metal shaft by applying multiple loads of cyclic rotational bending stress and axial compressive stress normalized by the yield stress on the processed part [1-3]. In the processing method, the local diameter-enlargement part is formed easily under a load condition of low compressive stress at room temperature, so the uselessness of the material because of cutting work and the mechanical damage in the part caused by welding can be avoided. The influences of various processing conditions and the mechanical properties of the used material on the diameter-enlargement behaviors are clarified, and a cycle parameter is proposed to evaluate the deformation behaviors under various processing conditions [4]. Further, the fatigue properties and safety against fatigue damage in the processed part are addressed [5-7]. However, only cold working has limitations regarding the processing efficiency and the maximum diameter-enlargement rate without fatigue damage generated in the foot of the processed part during the forming process. A large-scale processing machine is needed to improve the efficiency and the diameter-enlargement rate. Therefore, a new hot working diameter-enlargement processing method is proposed, in which the processed part is locally heated by a high-frequency induction-heating device and then formed by the processing method mentioned above. In the present research, a basic investigation is carried out to clarify the influence of the induction-heating conditions on the diameter-enlargement workability, and the diameter-enlargement rate and the processing efficiency obtained by the hot working are compared with those obtained by cold *working*.

II. Experiment

a) *Experimental Equipment*

Figure 1 shows an image diagram of a processing machine. The processing machine consists mainly of three components: (1) a component to set the bending angle, (2) *component* to load the axial-compressive force, and (3) an axial-rotary actuator. A test specimen was installed with an arbitrary distance between two holders by moving the parts loaded with an axial-compressive force. Fig. 2 shows a high-frequency induction-heating device to heat the processed *part* before forming starts.

b) *Experimental method*

A cold drawing S45C (Japanese Industrial Standard, JIS G4051-2009) round bar that was D_0 = 32 mm in diameter and L_0 = 155 mm in length was used as the test specimen. Table 1 presents the chemical composition of the material (mass %). Table 2 lists the mechanical properties of the sample material at room temperature.

Author α σ: Department of Mechanical Engineering, Faculty of Engineering, Ehime University, Matsuyama, Japan.
e-mails: zhu.xia.mx@ehime-u.ac.jp, ogi.keiji.mu@ehime-u.ac.jp

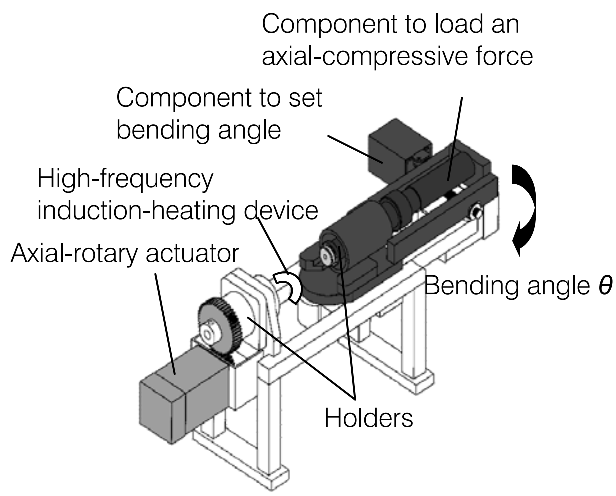


Figure 1: Image diagram of the processing machine

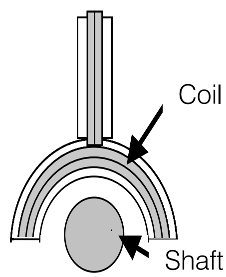


Figure 2: Schema of high-frequency induction-heating device

Table 1: Chemical compositions of S45C (mass

	C	Si	Mn	P	S
S45C	0.43	0.21	0.61	0.011	0.006

In the high-frequency induction-heating experimental method, a test specimen was installed coaxially between two holders in the processing machine; the *specimen* was then rotated and locally heated by the high-frequency induction-heating device. At the end of the set heating time, the heating coil was removed. The distance between both holders at that point is defined as l_0.

In the diameter-enlargement processing experimental method, the test specimen was loaded with an axial-compressive stress of σ_c / σ_y, which is an axial- compressive stress normalized by yield stress σ_y, in the axial-compressive side. The specimen was rotated with a rotational speed ω after the heating experiment ends. Then, it is loaded gradually to a set bending angle θ. Until the local diameter-enlargement part is formed on the test specimen and its diameter reaches the required diameter-enlargement rate D/D_0, the values of θ, σ_c/σ_y, and ω are returned to zero.

An infrared thermometer and a laser Displacement meter, respectively, continuously measured the surface temperatures and changes in the distance l between both holders in the processed part.

Table 2: Mechanical properties of S45C at room temperature

Young's modulus E (GPa)	Yield strength σ_y (MPa)	Tensile strength σ_B (MPa)	Reduction In area φ (%)
210	643	756	32.8

Table 3: Diameter-enlargement processing conditions

Normalized axial-compressive stress σ_c/σ_y	0.95, 0.97, 1.0
Bending angle θ (degree)	3, 4, 5
Rotating speed ω (rpm)	40
Final number of revolution N_{20}	20
Distance between two holder l_0 (mm)	55

c) *Experimental conditions*

Constant heating conditions of 2.2 kW, 420 V, and 21.7 kHz were set by adjusting the voltage of the high-frequency power source. The heating times were 20 to 120 s. Table 3 presents the processing conditions. The processing conditions are the same as that used in the cold working method, to compare the different work abilities [8].

III. Experimental Results and Discussion

a) Surface temperature change in both specimen and holder

Figure 3 shows the changes in the maximum surface temperature on the processed part as the high-frequency induction-heating time was increased. In addition, the abscissa shows the distance from the left holder in the processing machine. The surface temperature rises as the heating time increases. In the temperature distribution, the temperature rise is the fastest in the center section of the processed part, which is right under the coil, and the temperature rise range extends with the increase in the heating time. The temperature at the left holder end also rises with the increase in the heating time, as shown in Fig. 4. This suggests that thermal energy transfers from the processed part to the holders via heat conduction, and loss of energy is confirmed.

Figure 5 shows the various temperature changes in the processed part just after heating ends, just before processing starts, and just after processing ends. However, the maximum surface temperatures rose rapidly with the increase in the initial heating time period in all cases, and the rising slopes of the temperature become gradual with a heating time > 60 s. Moreover, as shown in the figure, the surface temperature at the start of processing was lower than that at the end of processing with a heating time < 50 s; however, the surface temperature at the start of processing was higher than that at the end of processing and maintained the high level with a heating time >50 s. Under the conditions of a heating time > 50 s, the surface temperature rise was caused by a large plastic deformation advancing during the forming process, although thermal energy kept transferring to the atmosphere and the holder; thus, the heating was effective in promoting plastic deformation during the forming process. Moreover, the maximum surface temperature just before the beginning of processing decreased between 100 K and 200 K, compared with the temperature just after heating ended. Thus, it is necessary to consider the temperature decrease caused by the loss of thermal energy until the processing starts when setting the heating time or the heating temperature. Moreover, blue shortness is a brittle characteristic of steel involving the increase in tensile strength and hardness, decrease in percentage elongation, and percentage reduction in area at a temperature of 473 K to 573 K [9-10].

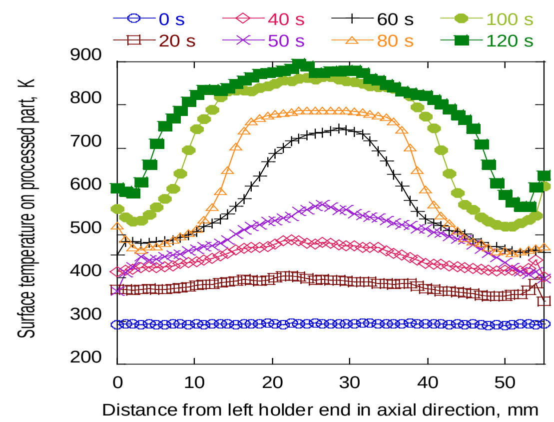


Figure 3: Changes in surface temperature distribution with increase in heating time

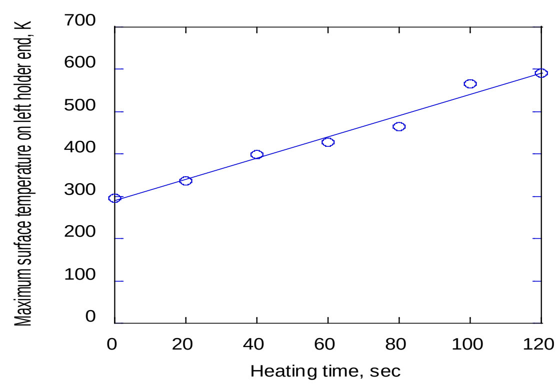


Figure 4: Changes in the maximum surface temperature on left holder end with the increase in heating time

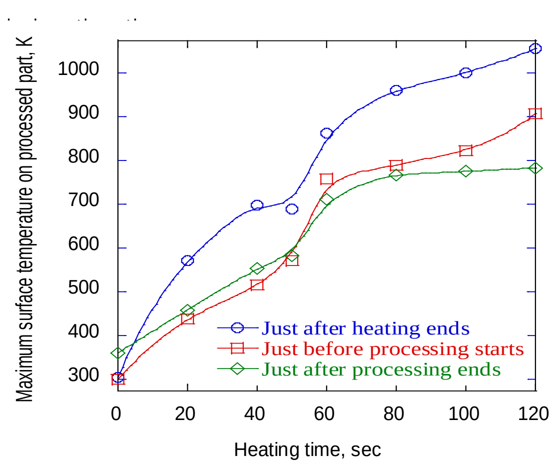


Figure 5: Changes in the maximum surface temperature on the processed part with the increase in heating time ($\theta = 3°$, $\sigma_c/\sigma_y = 0.97$, $N = 20$)

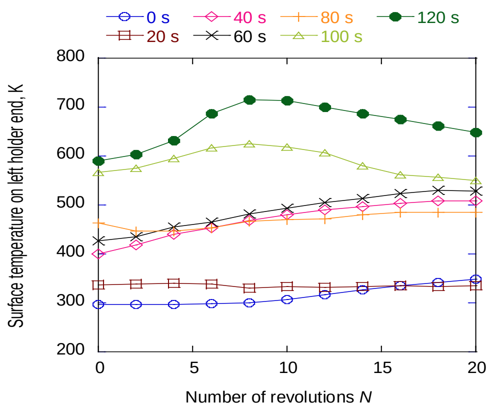


Figure 6: Changes in maximum surface temperature on the left holder end with the increase in number of revolutions in each heating time (θ = 3°, σ_c / σ_y = 0.97)

Figure 6 shows that the maximum surface temperature at the left holder end changed with an increase in the number of revolutions for each heating time under the conditions of θ = 3° and σ_c / σ_y = 0.97, and the Temperature passed into the blue shortness temperature range during the forming process, with a heating time of 40–100 s. However, Fig. 7 shows that the maximum surface temperature on the processed part passed into the blue shortness temperature range during the forming process with a heating time of 40–50 s. Thus, it is necessary to set heating conditions such that blue shortness is not generated in the test specimen and holder.

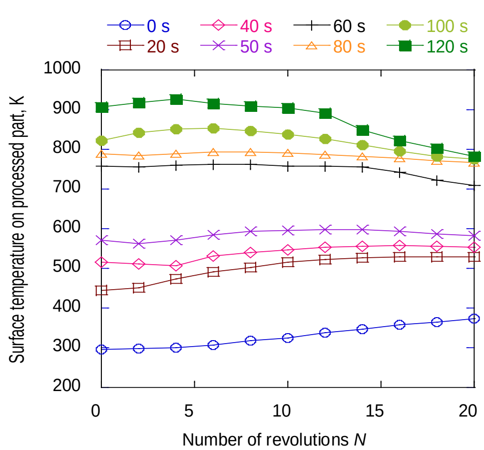


Figure 7: Change in maximum surface temperature on the processed part with the increase in number of revolutions in each heating time (θ = 3°, σ_c/σ_y = 0.97)

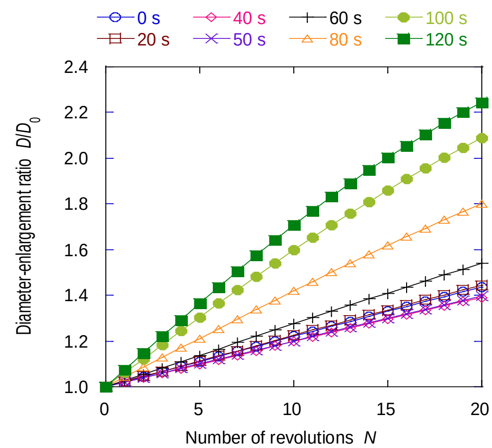


Figure 8: Diameter-enlargement deformation behaviors with increase in number of revolutions in each heating time (θ = 3°, σ_c/σ_y=0.97)

(a) Heating time = 0 sec (b) Heating time = 40 sec (c) Heating time = 120 sec

Figure 9: Photograph in part processed at heating time = 0 sec (cold working), 40 sec and 120 sec

b) *Influence of heating time on diameter-enlargement deformation behavior*

Figure 8 shows the behavior of the diameter-enlargement rate D/D0 with an increase in the number of revolutions *N* for each heating time. At a heating time of 20–50 s, the D20/D0 value at *N* = 20 with hot working was lower than that with cold working (heating time = 0) because of blue shortness, and the results shown in Fig. 8 agree well with the result shown in Fig. 7. However, at a heating time >50 s, a heating effect appeared in the diameter-enlargement deformation behavior compared with that obtained by cold working, and the slopes of D/D_0 increased rapidly with the increase in heating time. The D_{20}/D_0 obtained by hot working at a heating time of 120 s is significantly higher than that obtained by cold working; the D_{20}/D_0 value reached 2.25. Fig. 9 shows the test specimens heated under the different heating conditions with a heating time of 0 s (cold working), 40 s, and 120 s, but under the same processing conditions of θ = 3°, σ_c / σ_y = 0.97, *N* = 20. It was confirmed experimentally that heating is effective for the progress of diameter-enlargement deformation progress at a heating time of >50 s.

c) Formula for diameter-enlargement deformation behavior

Based on previous studies (6), the axial compression rate l/l_0, which is the change in the distance between both holders and the diameter-enlargement rate D/D_0 in the processed part can be expressed, respectively, by Eqs. (1) and (2).

$$l/l_0 = \exp\{\varepsilon_{p0}\{1-\exp(-N/N_0)\}\} \tag{1}$$

$$D/D_0 = \left[\exp\{\varepsilon_{p0}\{\exp(-N/N_0)-1\}\}\right]^{1/2} \tag{2}$$

Where ε_{p0} is the maximum average axial-plastic strain, which is approximately 3.0 except for the blue shortness temperature range. N_0 is a cycle parameter that can evaluate uniformly the processing conditions and can be calculated from the relation of $D/D_0 - N$ or $l/l_0 - N$ obtained through the processing experiments. The relation between N_0 and the normalized axial-compressive stress σ_c/σ_y in each bending angle θ is shown in Fig. 10 and is expressed by Eq. (3). Then, the relation between coefficients N_0^*, α, and the bending angle θ is shown in Fig. 11 and is expressed by Eqs. (4) and (5).

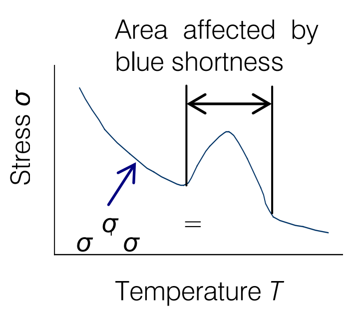
$$N_0 = N_0^* / (\sigma_c/\sigma_y)^{\alpha} \tag{3}$$

$$N_0^* = \hat{N}_0^* \theta^m \tag{4}$$

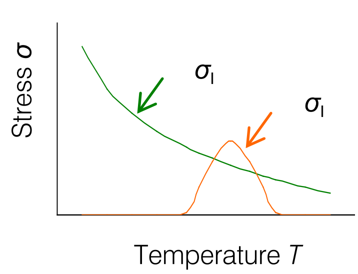
$$\alpha = \alpha_0 \theta^m \tag{5}$$

Table 4: Material constants included in Eq. (6)

$\hat{N}_0^*$	α_0^*	m
50	73	-0.75



(a) Conceptual diagram



(b) Decomposition diagram

Figure 12: Relation between stress and temperature

Table 5: Material constants included in Eqs. (7)- (8)

β_0	2.56×10^{-3}	β_1 (K^{-1})	-2.82×10^{-7}
K_0 (MPa)	1.86×10^{3}	K_1 (MPa/K)	-1.11
n_0	1.94×10^{-1}	n_1 (K^{-1})	-4.40×10^{-5}
C_1 (MPa)	6.90×10^{2}	C_2 (K^{-2})	-9.88×10^{-5}
C_3	5.04×10^{-1}	T_0 (K)	537

The relation between N_0 and the processing conditions of normalized axial-compressive stress σ_c/σ_y and bending angle θ is expressed by Eq. (6), obtained by substituting Eq. (4) and Eq. (5) in Eq. (3). Because N_0 is large, the processing requires more revolutions.

$$N_0 = \hat{N}_0^* \theta^m / (\sigma_c/\sigma_y)^{\alpha_0^* \theta^m} \tag{6}$$

The material constants included in Eq. (6) are listed in Table 4. However, the relation (8) between the stress σ of the sample material and the temperature T is shown in Fig. 12. Fig. 12(a) shows that the stress rises rapidly According to the increase in work hardening in the blue shortness temperature range. The relation between stress and temperature can be expressed by the sum of two stress components σ_I and σ_{II}, as shown in Fig. 12(b). That is, σ_I decreases monotonously for a temperature rise without the effect of blue shortness, and it is a stress component with the usual temperature dependency. Moreover, σ_{II} shows a stress component that increases according to blue shortness. The relation between stress σ and plastic strain ε_p in the total temperature range, including the blue shortness range, is shown in Eq. (7).

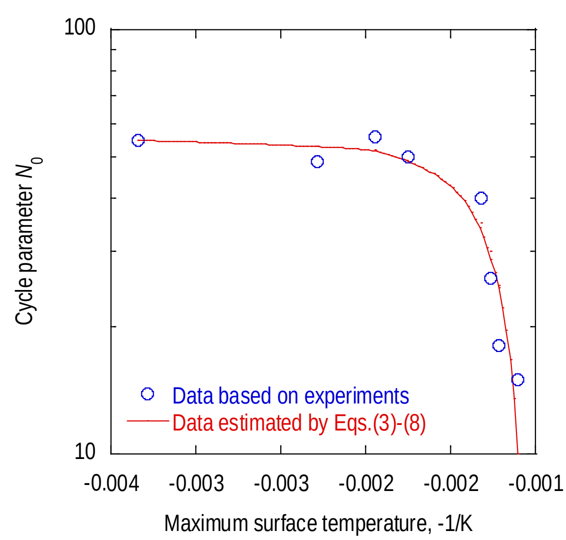


Figure 13: Relationship between cycle parameter and the maximum surface temperature just before processing starts

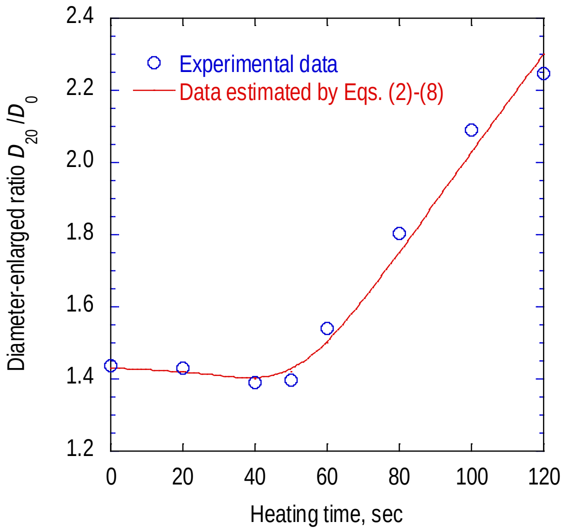


Figure 14: Changes of diameter-enlargement rate at number of revolution N=20 with the increase in heating time

$$\sigma = K(\varepsilon_p + \beta)^n + C_1 \exp\{C_2(T - T_0)^2\}\varepsilon_p^{C_3} \quad (7)$$

where β is the yield strain. The material constants K, β, and n included in Eq. (7) change linearly with temperature and are shown in Eqs. (8) – (10).

$$\beta = \beta_0 + \beta_1 T \quad (8)$$

$$K = K_0 + K_1 T \quad (9)$$

$$n = n_0 + n_1 T \quad (10)$$

The material constants included in Eqs. (7) - (8) are listed in Table 5. Figure 13 shows relation between N_0 and the maximum surface temperature just before processing starts. In the figure, the symbol O represents data obtained through the processing experiments, and the curve shows data estimated by Eqs. (3) – (8); the N0 estimated is in close agreement with the experiment data in all temperature ranges. Then, the curve (Fig. 14), which shows the relation between the diameter-enlargement rate D_{20}/D_0 estimated by Eqs. (2) – (10) and heating time, is in good agreement with the experimental data.

IV. Conclusion

In this research, diameter-enlargement processing experiments were conducted after locally heating the specimen with a high-frequency induction heating device installed in a diameter-enlargement processing machine. The heating conditions were clarified for achieving a higher diameter-enlargement rate and higher processing efficiency than those obtained by cold working. The main results obtained are as follows.

1. The diameter-enlargement rate obtained by hot working was more than twice that obtained by cold working. This rate is achieved by local high-frequency induction heating in just 120 s, which shows that hot working is effective for the diameter-enlargement forming process.
2. It is necessary to avoid heating in the temperature range of 473 K-573 K, because the diameter-enlargement rate and the processing efficiency decrease due to the generation of blue shortness.
3. Diameter-enlargement deformation behavior can be estimated approximately by the cycle parameter, which is considered the effect of blue shortness.

Acknowledgments

The present authors would like to thank Neturen Co., Ltd. (*http://www.k-neturen.co.jp/*) for providing a processing machine, and the authors also thank Ph. D. in Eng. K. Mori for his support.

The authors would like to thank Editage (*www.editage.jp*) for English language editing.

References Références Referencias

1. T. Iura, N. Okabe, X. Zhu, and K. Mori, "A New Cold Working with Local Superplastic Deformation for a Metal Bar " Proceedings of the 7th International Conference on Technology of Plasticity, Vol.1 , pp.493-498, 2002.
2. T. Iura, N. Okabe and X. Zhu, "Development of Novel Plastic Working Process for Producing a Collar on a Round Shaft Journal of the Japan Society Technology Plasticity", Vol.44, No.514, pp.45-49, 2003.
3. T. Iura, N. Okabe and X. Zhu, "Influence of Strength Properties on Diameter Increase for Processed Material during the Process of Enlarging a Partial Diameter", Journal of the Japan Society Technology Plasticity, Vol.46, No.531, pp.55-59, 2005.
4. N. Okabe, X. Zhu, K. Mori and T. Iura, "Application of Processing Method to Enlargement of Diameter of Hollow Round Bar as Shaft", Journal of the Japan Society Technology Plasticity, Vol.46, No.533, pp.90-94, 2005.
5. T. Iura, N. Okabe, and X. Zhu, "Fatigue Properties and Fatigue Damage in a Round Shaft with a Collar Formed by a Novel Processing Method for Enlarging Diameter", Journal of the Japan Society Technology Plasticity, Vol.45, No.516, pp. 35-39, 2004.
6. X. Zhu, N. Okabe, K. Ogi, M. Takahashi, "Fatigue Strength of Shaft with Diameter Enlarged Partially by Cyclic Bending and Axial Compressive Loading", Appl. Mech. Mater., Vols. 217-219, pp. 2346-2350, 2012.

7. The diameter- ahashi, K. Ogi, M. Takahashi, N. Okabe, "Investigation of Crack Generation in a Notch during Diameter-Enlargement Working Method Processing", Key Eng. Mater., Vol. 656-657, pp. 473-478, 2015.
8. N. Okabe, X. Zhu, K. Mori and T. Iura, "Application of the Processing Method for Enlarging Partial Diameter to Shaft for Practical Use", Journal of the Japan Society Technology Plasticity, Vol.47, No.540, pp.49-53, 2006.
9. Japan Institute of Invention and Innovation Japanese BLAC to the OECD Corp., Metal heat treatment, 2006.
10. H. Tachiya, T. Aramoto, K. Takagi, A. Hojo and A. Chatani, "Temperature Dependent Constitutive Equation for Carbon Steels with Consideration of Blue Brittleness", Journal of the Japan Society of Mechanical Engineers (volume A), Vol.71, No.703, pp.435-442, 2006.

This page is intentionally left blank

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 18 Issue 2 Version 1.0 Year 2018
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN:2249-4596 Print ISSN:0975-5861

Electromagnetelastic Actuator for Nanomechanics

By Afonin SM

National Research University of Electronic Technology

Abstract- From the structural-parametric model of the electromagnetoelastic actuator we obtain the parametric structural schematic diagram and the matrix transfer function, the characteristics of the electromagnetoelastic actuator for the nanomechanics. The generalized parametric structural schematic diagram, the matrix transfer function of the electromagnetoelastic actuator is described with using its physical parameters and external load.

Keywords: *electromagnetoelastic actuator; structural-parametric model; nanodisplacement; piezoactuator; parametric structural schematic diagram; matrix transfer function.*

GJRE-A Classification: *FOR Code: 100799*

Electromagnetelastic Actuator for Nanomechanics

Afonin SM

Abstract- From the structural-parametric model of the electromagnetoelastic actuator we obtain the parametric structural schematic diagram and the matrix transfer function, the characteristics of the electromagnetoelastic actuator for the nanomechanics. The generalized parametric structural schematic diagram, the matrix transfer function of the electromagnetoelastic actuator is described with using its physical parameters and external load.

Keywords: electromagnetoelastic actuator; structural-parametric model; nanodisplacement; piezoactuator; parametric structural schematic diagram; matrix transfer function.

I. Introduction

The electromagnetoelastic actuator for piezoelectric, piezomagnetic, electrostriction, magnetostriction effects is used for the precise adjustment in the nanomechanics, the nanotechnology, the adaptive optics [1–32]. The piezoactuator on the inverse piezoeffect is serves for the actuation of mechanisms or the management, converts the electrical signals into the displacement and the force [1–8]. The piezoactuator for the nanomechanics is provided the displacement from nanometers to tens of micrometers, a force to 1000 N. The piezoactuator is used in the nanomechanics and the nanotechnology for the scanning tunneling microscopes, the scanning force microscopes and the atomic force microscopes [14–32].

In the present paper the generalized structural-parametric model and the generalized parametric structural schematic diagram of the electro-magnetoelastic actuator are constructed by solving the equation of the electromagnetolasticity, the wave equation with the Laplace transform, the boundary conditions on loaded working surfaces of the actuator, the strains along the coordinate axes. The transfer functions and the parametric structural schematic diagrams of the piezoactuator are obtained from the generalized structural-parametric model. In [6, 7] was determined the solution of the wave equation of the piezoactuator. In the [14–16, 30] were obtained the structural-parametric models, the schematic diagrams for simple piezoactuator and this models were transformed to the structural-parametric model of the electromagnetoelastic actuator. The structural-parametric model of the electroelastic actuator was determined in contrast electrical equivalent circuit for calculation of piezoelectric transmitter and receiver [9–12]. In [8, 27] was used the transfer functions of the piezoactuator for the decision problem absolute stability conditions for a system controlling the deformation of the electromagnetoelastic actuator. The elastic compliances and the mechanical and adjusting characteristics of the piezoactuator were found in [18, 21 – 23, 28, 29] for calculation its transfer functions and the structural-parametric models. The structural-parametric model of the multilayer and compound piezoactuator was determined in [18–20]. In this paper is solving the problem of building the generalized structural parametric model and the generalized parametric structural schematic diagram of the electro-magnetoelastic actuator for using the equation of electromagnetoelasticity.

Author: National Research University of Electronic Technology (Moscow Institute of Electronic Technology, MIET), Moscow, Russia.
e-mail: learner01@mail.ru

II. Structural-Parametric Model

The general structural-parametric model and the parametric structural schematic diagram of the electromagnetoelastic actuator are obtained. In the electroelastic actuator are presented six stress components T_1, T_2, T_3, T_4, T_5, T_6, the components T_1 – T_3 are related to extension-compression stresses, T_4 – T_6 to shear stresses. For the electroelastic actuator its deformation corresponds to stressed state. In piezoceramics PZT the matrix state equations [12, 14] connected the electric and elastic variables have the form two equations, then the first equation describes the direct piezoelectric effect, the second - the inverse piezoelectric effect

$$\mathbf{D} = \mathbf{dT} + \boldsymbol{\varepsilon}^T \mathbf{E} \qquad (1)$$

$$\mathbf{S} = \mathbf{s}^E \mathbf{T} + \mathbf{d}^t \mathbf{E} \qquad (2)$$

where $\mathbf{D}$ is the column matrix of electric induction; $\mathbf{S}$ is the column matrix of relative deformations; $\mathbf{T}$ is the column matrix of mechanical stresses; $\mathbf{E}$ is the column matrix of electric field strength; $\mathbf{s}^E$ is the elastic compliance matrix for $E = \text{const}$; $\boldsymbol{\varepsilon}^T$ is the matrix of dielectric constants for $T = \text{const}$; $\mathbf{d}^t$ is the transposed matrix of the piezoelectric modules.

The piezoactuator (piezoplate) has the following properties: δ is the thickness, *h* is the height, *b* is the width, respectively $l=\{\delta,h,b$ the length of the piezoactuator for the longitudinal, transverse and shift piezoeffects. The direction of the polarization axis P, i.e., the direction along which polarization was performed, is usually taken as the direction of axis 3. The equation of the inverse piezoeffect for controlling voltage [6, 12] has the form

$$S_i = d_{mi}\Psi_m(t) + s_{ij}^{\Psi} T_j(x,t)$$
$$S_i = \partial\xi(x,t)/\partial x\,,\ \Psi_m(t) = E_m(t) = U(t)/\delta \tag{3}$$

where S_i is the relative displacement of the cross section of the piezoactuator along axis *i*, $\Psi_m(t)$ is the control parameter along axis *m*, d_{mi} is the coefficient of the electromagnetolasticity (for example the piezomodule), $E_m(t)$ is the electric field strength along axis *m*, $U(t)$ is the voltage between the electrodes of actuator, s_{ij}^{Ψ} is the elastic compliance for $\Psi = \text{const}$, $T_j(x,t)$ is the mechanical stress along axis *j* and *i, j* = 1, 2, … , 6; *m* = 1, 2, 3. The main size $l=\{\delta,h,b$ for the piezoactuator is respectively, the thickness, the height, the width for the longitudinal, transverse, shift piezoeffects.

For calculation of actuator is used the wave equation [6, 7, 12, 14] for the wave propagation in a long line with damping but without distortions. After Laplace transform is obtained the linear ordinary second-order differential equation with the parameter *p*, whereupon the original problem for the partial differential hyperbolic equation of type using the Laplace transform is reduced to the simpler problem [6, 13] for the linear ordinary differential equation

$$\frac{d^2\Xi(x,p)}{dx^2} - \gamma^2\Xi(x,p) = 0 \tag{4}$$

with its solution

$$\Xi(x,p) = Ce^{-x\gamma} + Be^{x\gamma} \tag{5}$$

where $\Xi(x,p)$ is the Laplace transform of the displacement of the section of the piezoactuator, $\gamma = p/c^{\Psi} + \alpha$ is the propagation coefficient, c^{Ψ} is the sound speed for $\Psi = \text{const}$, α is the damping coefficient of the wave, Ψ is the control parameter: *E* is the electric field strength for the voltage control, *D* is the electrical induction for the current control, *H* is the magnet field strength.

From (3), (4), the boundary conditions on loaded surfaces, the strains along the axes the system of equations for the generalized structural-parametric model and the generalized parametric structural schematic diagram Figure 1 of the actuator are determined

$$\Xi_1(p) = \left(\frac{1}{M_1 p^2}\right)\left\{-F_1(p) + \left(\frac{1}{\chi_{ij}^{\Psi}}\right)\left[\begin{matrix} d_{mi}\Psi_m(p) - \\ \left(\frac{\gamma}{\operatorname{sh}(l\gamma)}\right)\left[\operatorname{ch}(l\gamma)\Xi_1(p) - \Xi_2(p)\right]\end{matrix}\right]\right\}$$

$$\Xi_2(p) = \left(\frac{1}{M_2 p^2}\right)\left\{-F_2(p) + \left(\frac{1}{\chi_{ij}^{\Psi}}\right)\left[\begin{matrix} d_{mi}\Psi_m(p) - \\ \left(\frac{\gamma}{\operatorname{sh}(l\gamma)}\right)\left[\operatorname{ch}(l\gamma)\Xi_2(p) - \Xi_1(p)\right]\end{matrix}\right]\right\} \tag{6}$$

Where $\chi_{ij}^{\Psi} = \frac{s_{ij}^{\Psi}}{S_0}$ $d_{mi} = \begin{cases} d_{33}, d_{31}, d_{15} \\ g_{33}, g_{31}, g_{15} \\ d_{33}, d_{31}, d_{15}\end{cases}$, $\Psi_m = \begin{cases} E_3, E_3, E_1 \\ D_3, D_3, D_1 \\ H_3, H_3, H_1\end{cases}$, $s_{ij}^{\Psi} = \begin{cases} s_{33}^E, s_{11}^E, s_{55}^E \\ s_{33}^D, s_{11}^D, s_{55}^D \\ s_{33}^H, s_{11}^H, s_{55}^H\end{cases}$, $l=\{\delta,h,b$, $c^{\Psi} = \{c^E, c^D, c^H$, $\gamma^{\Psi} = \{\gamma^E, \gamma^D, \gamma^H$, d_{mi} is the coefficient of the electromagnetolasticity (for example the piezomodule or the coefficient of the magnetostriction).

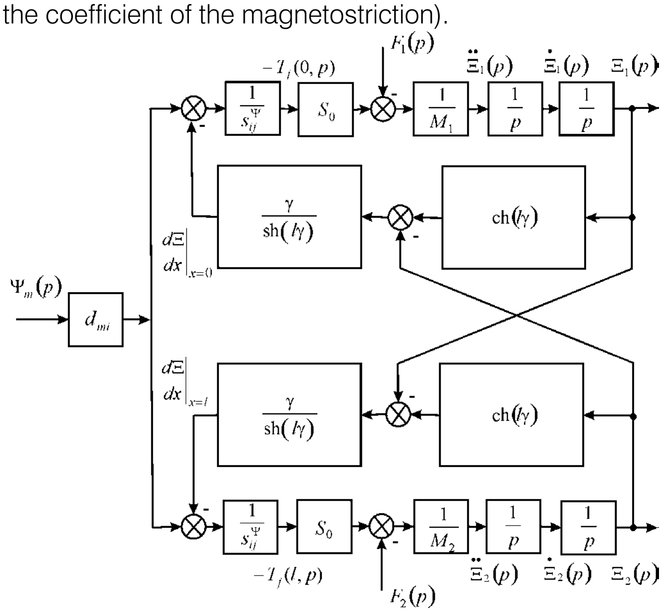


Figure 1: Generalized parametric structural schematic diagram of the electromagnetoelastic actuator

The generalized transfer functions of the electromagnetoelastic actuator are the ratio of the Laplace transform of the displacement of the face actuator and the Laplace transform of the corresponding control parameter or the force at zero initial conditions.

III. Matrix Transfer Function

The matrix transfer function of the electromagnetoelastic actuator for the nanomedicine and the nanotechnology is deduced from its structural-parametric model (6) in the following form

$$\begin{pmatrix} \Xi_1(p) \\ \Xi_2(p) \end{pmatrix} = \begin{pmatrix} W_{11}(p) & W_{12}(p) & W_{13}(p) \\ W_{21}(p) & W_{22}(p) & W_{23}(p) \end{pmatrix} \begin{pmatrix} \Psi_m(p) \\ F_1(p) \\ F_2(p) \end{pmatrix} \quad (7)$$

For $m << M_1$ and $m << M_2$ the static displacement of the faces of the piezoactuator for the transverse piezo effect are obtained

$$\xi_1(\infty) = \lim_{\substack{p \to 0 \\ \alpha \to 0}} \frac{pW_{11}(p)U_0}{\delta p} = \frac{d_{31} h U_0 M_2}{\delta(M_1 + M_2)} \quad (8)$$

$$\xi_2(\infty) = \lim_{\substack{p \to 0 \\ \alpha \to 0}} \frac{pW_{21}(p)U_0}{\delta p} = \frac{d_{31} h U_0 M_1}{\delta(M_1 + M_2)} \quad (9)$$

For the piezoactuator from PZT under the transverse piezoeffect at $m << M_1$, $m << M_2$, $d_{31} = 2.5 \cdot 10^{-10}$ m/V, $h/\delta = 20$, $U = 30$ V, $M_1 = 2$ kg, $M_2 = 8$ kg the static displacements of the faces are determined $\xi_1(\infty) = 120$ nm, $\xi_2(\infty) = 30$ nm, $\xi_1(\infty) + \xi_2(\infty) = 150$ nm.

For the approximation of the hyperbolic cotangent by two terms of the power series in transfer function (7) the following expressions of the transfer function of the piezoactuator is obtained for the elastic-inertial load at $M_1 \to \infty$, $m << M_2$ under the transverse piezoeffect

$$W(p) = \frac{\Xi_2(p)}{U(p)} = \frac{d_{31} h/\delta}{\left(1 + C_e/C_{11}^E\right)(T_t^2 p^2 + 2T_t \xi_t p + 1)}$$

$$T_t = \sqrt{M_2/\left(C_e + C_{11}^E\right)}, \quad \xi_t = \alpha h^2 C_{11}^E \Big/ \left(3c^E \sqrt{M\left(C_e + C_{11}^E\right)}\right) \quad (10)$$

where $U(p)$ is the Laplace transform of the voltage, T_t is the time constant and ξ_t is the damping coefficient of the piezoactuator. The expression for the transient response of the voltage-controlled piezoactuator for the elastic-inertial load is determined

$$\xi(t) = \xi_m \left(1 - \frac{e^{-\frac{\xi_t t}{T_t}}}{\sqrt{1 - \xi_t^2}} \sin(\omega_t t + \varphi_t) \right) \quad (11)$$

$$\xi_m = \frac{d_{31}(h/\delta)U_m}{1 + C_e/C_{11}^E}, \quad \omega_t = \frac{\sqrt{1 - \xi_t^2}}{T_t}, \quad \varphi_t = \operatorname{arctg}\left(\frac{\sqrt{1 - \xi_t^2}}{\xi_t}\right)$$

Where ξ_m the steady-state value of displacement of the piezoactuator is, U_m is the amplitude of the voltage. For the voltage-controlled piezoactuator from the piezoceramics PZT under the transverse piezoelectric effect for the elastic-inertial load $M_1 \to \infty$, $m << M_2$ and input voltage with amplitude $U_m = 25$ V at $d_{31} = 2.5 \cdot 10^{-10}$ m/V, $h/\delta = 20$, $M_2 = 4$ kg, $C_{11}^E = 2 \cdot 10^7$ N/m, $C_e = 0.5 \cdot 10^7$ H/m are obtained values $\xi_m = 100$ nm, $T_t = 0.4 \cdot 10^{-3}$ c. The characteristics of the piezoactuator are described with using its physical parameters and external load.

IV. Results and Discussions

The structural-parametric model and parametric structural schematic diagrams of the voltage-controlled piezoactuator for the longitudinal, transverse and shift piezoeffects are determined from the generalized structural-parametric model of the electro-magnetoelastic actuator with the replacement of the following parameters.

$$\Psi_m = \{E_3, E_3, E_1 \ , \ d_{mi} = \{d_{33}, d_{31}, d_{15} \ , \ s_{ij}^{\Psi} = \{s_{33}^E, s_{11}^E, s_{55}^E \ , \ l = \{\delta, h, b$$

The generalized structural-parametric model, the generalized parametric structural schematic diagram and the matrix transfer function of the electro-magnetoelastic actuator are obtained from the solutions of the equation of the electromagnetoelasticity, the Laplace transform and the linear ordinary differential equation of the second order.

From the generalized matrix transfer function of the electromagnetoelastic actuator after algebraic transformations are constructed the matrix transfer function of the piezoactuator for the longitudinal, transverse and shift piezoeffects.

V. Conclusions

The generalized structural-parametric model, the generalized parametric structural schematic diagram, the matrix transfer function of the electromagnetoelastic actuator for the nanomechanics are obtained.

The structural-parametric model, the matrix transfer function and the parametric structural schematic diagram of the piezoactuator for the transverse, longitudinal, shift piezoeffects are obtained from the generalized structural-parametric model of the electro-magnetoelastic actuator. From the solution of the equation of the electromagnetolasticity, the wave equation with the Laplace transform and the deformations along the axes the generalized structural-parametric model and the generalized parametric structural schematic diagram of the electro-magnetoelastic actuator are constructed for the control systems in the nanomechanics. The deformations of the actuator are described by using the matrix transfer function of the electromagnetoelastic actuator.

References Références Referencias

1. Schultz J, Ueda J, Asada H (2017) Cellular Actuators. Butterworth-Heinemann Publisher, Oxford, 382 p.
2. Uchino K (1997) Piezoelectric actuator and ultrasonic motors. Kluwer Academic Publisher, Boston, MA, 1997, 347 p.

3. Przybylski J (2015) Static and dynamic analysis of a flex tensional transducer with an axial piezoelectric actuation, engineering structures 84: 140–151, doi: 10.1016/j.engstruct.2014.11.025.
4. Ueda J, Secord T, Asada HH (2010) large effective-strain piezoelectric actuators using nested cellular architecture with exponential strain amplification mechanisms. IEEE/ASME Transactions on Mechatronics 15(5): 770-782, doi: 10.1 109/ TMECH.2009.2034973.
5. Karpelson M, Wei G-Y, Wood RJ (2012) Driving high voltage piezoelectric actuators in microrobotic applications. Sensors and Actuators A: Physical 176: 78-89, doi: 10.1016/j.sna.2011.11.035.
6. Afonin SM (2006) Solution of the wave equation for the control of an elecromagnetoelastic transduser. Doklady mathematics 73(2):307-313, doi: 10.11 34/ S1064562406020402.
7. Afonin SM (2008) Structural parametric model of a piezoelectric nanodisplacement transduser. Doklady physics 53(3): 137-143, doi: 10.1134/ S10 28335808030063.
8. Afonin SM (2014) Stability of strain control systems of nano-and micro displacement piezotransducers. Mechanics of solids 49(2): 196-207, doi: 10. 31 03/ S0025654414020095.
9. Talakokula V, Bhalla S, Ball RJ, Bowen CR, Pesce GL, Kurchania R, Bhattacharjee B, Gupta A, Paine K (2016) Diagnosis of carbonation induced corrosion initiation and progressionin reinforced concrete structures using piezo-impedance transducers. Sensors and Actuators A: Physical 242: 79-91, doi: 10.1016/j.sna.2016.02.033.
10. Yang Y, Tan, L (2009) Equivalent circuit modeling of piezoelectric energy harvesters. Journal of intelligent material systems and structures 20(18): 2223-2235.
11. Cady WG (1946) Piezoelectricity: An introduction to the theory and applications of electromechancial phenomena in crystals. McGraw-Hill Book Company, New York, London, 806 p.
12. Physical Acoustics: Principles and Methods. Vol.1. Part A. Methods and Devices. Ed.: Mason W (1964). Academic Press, New York, 515 p.
13. Zwillinger D (1989) Handbook of Differential Equations. Academic Press, Boston, 673 p.
14. Afonin SM (2015) Structural-parametric model and transfer functions of electroelastic actuator for nano- and micro displacement. Chapter 9 in Piezoelectrics and Nanomaterials: Fundamentals, Developments and Applications. Ed. Parinov IA. Nova Science, New York, pp. 225-242.
15. Afonin SM (2016) Structural-parametric model electromagnetoelastic actuator nano- and micro displacement for precision engineering. Precision Engineering. Engineering and Technology 3(6): 110-119.
16. Afonin SM (2016) Structural-parametric models and transfer functions of electromagnetoelastic actuators nano- and micro displacement for mechatronic systems. International Journal of Theoretical and Applied Mathematics 2(2): 52-59, doi: 10.11648/j.ijtam.20160202.15.
17. Afonin SM (2002) Parametric structural diagram of a piezoelectric converter. Mechanics of solids 37(6): 85-91.
18. Afonin SM (2003) Deformation, fracture, and mechanical characteristics of a compound piezoelectric transducer. Mechanics of solids 38(6): 78-82.
19. Afonin SM (2004) Parametric block diagram and transfer functions of a composite piezoelectric transducer. Mechanics of solids 39(4): 119-127.
20. Afonin SM (2005) Generalized parametric structural model of a compound elecromagnetoelastic transduser. Doklady physics 50(2): 77-82 doi: 10. 1134/1.1881716.
21. Afonin SM (2010) Design static and dynamic characteristics of a piezoelectric nanomicro-transducers. Mechanics of solids 45(1): 123-132, doi: 10.3103/S0025654410010152.
22. Afonin SM (2011) Electro mechanical deformation and transformation of the energy of a nano-scale piezomotor. Russian engineering research 31(7): 638-642, doi: 10.3103 /S1068798X11070033.
23. Afonin SM (2011) Electroelasticity problems for multilayer nano- and micro motors. Russian engineering research 31(9): 842-847, doi: 10.3 103/ S1068798X11090036.
24. Afonin SM (2012) Nano- and micro-scale piezomotors. Russian engineering research 32(7-8): 519-522, doi:10.3103/S1068798X12060032.
25. Afonin SM (2015) Optimal control of a multilayer submicromanipulator with a longitudinal piezo effect. Russian engineering research 35(12): 907-910, doi: 10.3103/S1068798X15120035.
26. Afonin SM (2015) Block diagrams of a multilayer piezoelectric motor for nanomicrodisplacements based on the transverse piezoeffect. Journal of computer and systems sciences international, 54(3): 424-439, doi: 10.113 4/S1064230715020021.
27. Afonin SM (2006) Absolute stability conditions for a system controlling the deformation of an elecro-magnetoelastic transduser. Doklady mathematics 74(3):943-948, doi: 10.1134/S106 456 2406060391.
28. Afonin SM (2007) Elastic compliances and mechanical and adjusting characteristics of composite piezoelectric transducers," Mechanics of solids 42(1):43-49, doi: 10.3103/S0025654407010 062.
29. Afonin SM (2009) Static and dynamic characteristics of a multy-layer electroelastic solid. Mechanics of solids 44(6):935-950, doi: 10.3103/S0025654409060 119.

30. Afonin SM (2017) Structural-parametric model electromagnetoelastic actuator nanodisplacement for mechatronics. International Journal of Physics 5(1): 9-15. doi: 10.12691/ijp-5-1-27.
31. Springer Handbook of Nanotechnology. Ed. by Bhushan B (2004) Springer, Berlin, New York, 1222 p.
32. Encyclopedia of Nanoscience and Nanotechnology. Ed. by Nalwa HS (2004) American Scientific Publishers, Calif.

This page is intentionally left blank

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 18 Issue 2 Version 1.0 Year 2018
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN:2249-4596 Print ISSN:0975-5861

Effect of Local Dynamic Stability of a Ploydyne Cam with Translated Follower on Lyapunov Exponent Parameter over a Range of Speeds

By Dr. Louay S. Yousuf
Department of Mechanical Engineering San Diego State University

Abstract- This study quantized the relationship between local dynamic stability and the variation in cam rotational speeds. The dynamic analysis presents follower displacement driven by a cam rotating at a uniform angular velocity. There is a clearance between the follower and the guide. Maximum finitetime Lyapunov exponents were estimated to quantify local dynamic stability. Local stability of a follower attractor in the ydirection was shown to be achieved over multiple cam speeds. The variation in cam rotational speeds was associated with significant changes in Lyapunov exponent values. The numerical part of the dynamic model was investigated using Solid Works simulations. A Solid Works simulation is developed for the planar case using the block commands. Diferent follower guides' clearances have been used in the simulations. An experimental set up is developed to capture the general planar motion of the cam and follower. The measures the follower positions are obtained through high-resolution optical encoders (markers). A good agreement between numerical and experimental parts was obtained.

Keywords: nonlinear dynamic, local stability, camfollower mechanism, lyapunov exponent.

GJRE-A Classification: FOR Code: 091399

EFFECTOFLOCALDYNAMICSTABILITYOFAPLOYDYNECAMWITHTRANSLATEDFOLLOWERONLYAPUNOVEXPONENTPARAMETEROVERARANGEOFSPEEDS

Strictly as per the compliance and regulations of:

Effect of Local Dynamic Stability of a Ploydyne Cam with Translated Follower on Lyapunov Exponent Parameter over a Range of Speeds

Dr. Louay S. Yousuf

Abstract- This study quantized the relationship between local dynamic stability and the variation in cam rotational speeds. The dynamic analysis presents follower displacement driven by a cam rotating at a uniform angular velocity. There is a clearance between the follower and the guide. Maximum finite-time Lyapunov exponents were estimated to quantify local dynamic stability. Local stability of a follower attractor in the y-direction was shown to be achieved over multiple cam speeds. The variation in cam rotational speeds was associated with significant changes in Lyapunov exponent values. The numerical part of the dynamic model was investigated using Solid Works simulations. A Solid Works simulation is developed for the planar case using the block commands. Diferent follower guides' clearances have been used in the simulations. An experimental set up is developed to capture the general planar motion of the cam and follower. The measures the follower positions are obtained through high-resolution optical encoders (markers). A good agreement between numerical and experimental parts was obtained.

Keywords: nonlinear dynamic, local stability, cam-follower mechanism, lyapunov exponent.

I. Introduction

A cam is a mechanical device which is used to transmit the motion to the follower. The proposed cam can be used in motor car camshafts to operate the engine valves. Recently, much research effort has been spent to study the contact-impact problem. UNLUSOY and TUMER, [1]. derived the exact quasi-linear solution to represent the non-linear behavior of cam mechanism at different cam speeds. The critical examination of the simulation has been made by using the equivalent viscous damper instead of Coulomb friction model. Hamidzadeh and Dehghani, [2]. used Hill's infinite determinant method to present a solution of linear, second-order, ordinary differential equation for different rotational speeds. They found that the system is stable for low values of cam rotational speeds. A few unstable regions are occurred when the speed is increased gradually. The effect of both operational speed and damping on the dynamic stability has been determined. Tounsi et-al, [3] presented the multiple scales method to resolve the equation of motion unstable regimes. They calculated the instability regions in order to avoid of the exible cam mechanism of stable and dangerous working velocities. Cveticanin, [4]. described the mathematical model of cam-follower mechanism with two coupled non-linear, ordinary second-order differential equation. He developed new criteria for designing the cam profile based on the stable motion. Gue et al, [5]. applied the Fourier spectrum tool on cam acceleration based on frequency domain. The dynamic response at low frequency range has been related to different cam rotational speeds such as (700, 900, and 1100) rpm. Hsu and Pisano, [6]. Investigated the simulation of contact forces at three different speeds (660, 1650, and 2500) rpm of a finger-follower cam system. They determined the contact position between the cam and the follower by using the constrained equation method. The force at low speeds is employed to derive the dynamic Coulomb friction coefficients at contact points. chew and chuang, [7]. Implemented the generalized Lagrange multiplier method of cam-follower systems over a range of cam speeds. The results are checked by using a second approach of nonlinear programming technique. Fabien et-al, [8]. Explained a linear quadratic optimal control theory to design a high-speed of Dwell-Rise-Dwell (D-R-D) cams. Three approaches of D-R-D cam design are presented. In the first approach, the cam designed to be optimal at a fixed operating speed. In the second approach, the cam profile is determined by minimizing the sum of quadratic cost function over a range of discrete speeds. The third technique uses trajectory sensitivity minimization to design a cam which is insensitive to speed variations. Jiang et-al, [9]. Formulated the problems of minimizing vibrations in high-speed cam-follower systems over a range of speeds (800-3600) rpm. A universal Hermite cam displacement is suggested. Alzate et-al, [10] detected the sudden transition to chaos in a radial cam and a at faced follower. They observed that the follower detaches from the cam under the variation of cam rotational speeds. Yan et-al, [11]. Derived the equation of motion for a cam-follower system by using variable cam-input angular velocity. They found that peak values of follower output motion have been decreased by using proper cam-input trajectories. Bagci and Kurnool, [12]. Presented a Fourier series-Laplace transform to find the follower response at any time and at any cycle. They

Author: Assistant Professor Department of Mechanical Engineering San Diego State University 5500 Campanile Drive San Diego, CA 92182 1323 USA. e-mails: louaysabah1979@gmail.com, lalroomi@sdsu.edu

measured the critical cam speeds and follower jump conditions. Many researches have been done to reveal the effect of Lyapunov exponents on human-gait locomotion. The aim of this paper is to implement Lyapunov analyses to characterize stability of nonlinear dynamic.

II. Simulation Procedure

The cam, roller-follower, and guides are designed in a Solid Works program using the experimental dimensions of existing mechanisms, [13]. A simulation was carried out for the planar case using the block commands. The general dimensions of the cam, follower, and its guides are measured in (mm) and are shown in Fig. 1. Different follower guide's clearances such as C = 0.3, 0.5, 1, 1.5, and 2 mm have been used in the simulations. Fig. 2 shows the clearance between follower and its guide. The follower with clearance has three degrees of freedom translation in x, y directions and rotation about z axis. A marker has been stick on the follower by choosing a suitable point, which has the coordinates (x: 0, y: 272 mm, z: 0), as indicated in Fig. 1. The force expression function is:

$$F = a - b\Delta \quad (1)$$

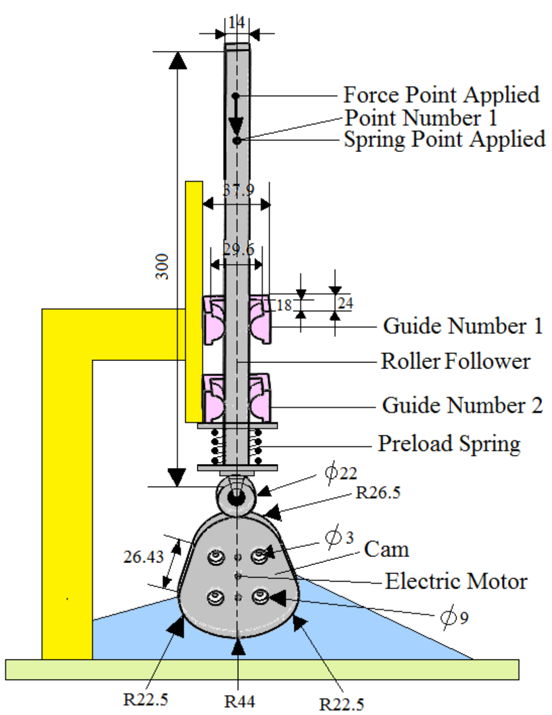


Figure 1: General Dimensions of Cam, Follower, and Guides

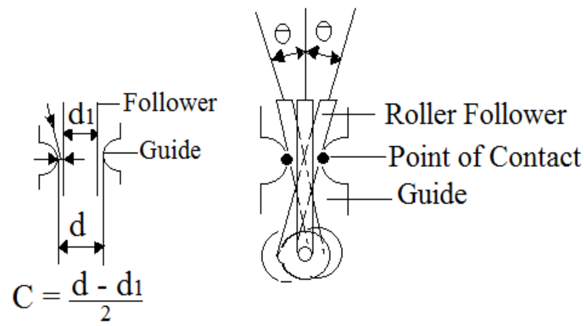


Figure 2: Schematic Diagram Illustrating Follower Guide's Clearance

Where, a = 1.7508 (N), b = 0.038 N/mm. The first term (a) represents the initial preload to avoid follower jumping during high speeds. The second term (b) represents the spring force varying with each position of the follower motion.

The contact force is defined as:

$$Fc = K\delta^n + \zeta\delta^n\dot{\delta} \quad (2)$$

The impact parameters that used in the Solidworks simulation are indicated in Table 1.

Table 1: Simulation Contact Parameters

Simulation Parameters		
Parameter's Definition	Value	Unit
Kinematic Sliding Velocity	10.16	mm/s
Kinematic Coefficient of Friction	0.2	—
Static Sliding Velocity	0.1	mm/s
Static Coefficient of Friction	0.3	—
Contact Bodies Stifiness	1100049.92	N/mm
Exponent	2	—
Max Damping	0.58839681	N/(mm/s)
Penetration	0.1	mm
Frame Per Second	500	—

III. Quantifying Local Dynamic Stability

The local dynamic stability of a cam-follower is quantifed by calculating Lyapunov exponent values. Maximum finite-time Lyapunov Exponents were calculated based on the algorithm published by Rosenstein et al. [14]. The dynamic analysis was constructed by using the data of follower displacement. A valid state space is any vector space containing a suficient number of independent coordinates, [15]. An appropriate state space can be reconstructed from a single time series as in the equation below:

$$X(t) = [x(t), x(t+T), x(t+2T), ..., x(t+(d_E-1)T)] \quad (3)$$

Time delay (T) and the embedding dimension (dE) are necessary for the nonlinear analysis. A computer algorithms was carried out to calculate the time delay and the embedding dimension. Time delay is an integer number between two samples from time series. If the time series represent a continuous on with samples taken every Δt seconds, then the delay parameter may be expressed as, [16]:

$$\tau = T\Delta t \quad (4)$$

Time delay was calculated from Average Mutual Information (AMI) algorithm. The time delay has been chosen from first minimum of the (AMI) analysis, as shown in Fig. 3.

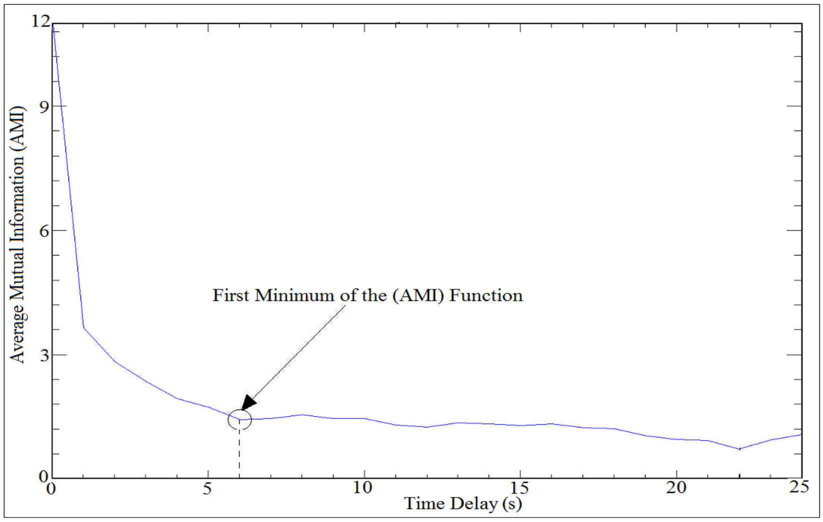


Figure 3: Average Mutual Information (AMI) Algorithm with Time Delay

With non-periodic systems and large value of τ, successive delay coordinates may become causally unrelated, and the reconstruction is no longer representative of the true dynamics, [16]. A related difficulty with attractor reconstruction involves the choice of dE. The embedding dimension is the algorithm which determines the global number of a space data vectors. It converts a single time series into a multidimensional object in an embedding space vectors. dE is usually estimated greater than twice the topological dimension (m) as:

$$d_E > 2m \tag{5}$$

Embedding dimension was computed from a Global False Nearest Neighbors (GFNN) algorithm. GFNN compares the distances between neighboring trajectories in the reconstructed state space at successively higher dimensions, as illustrated in Fig.4.

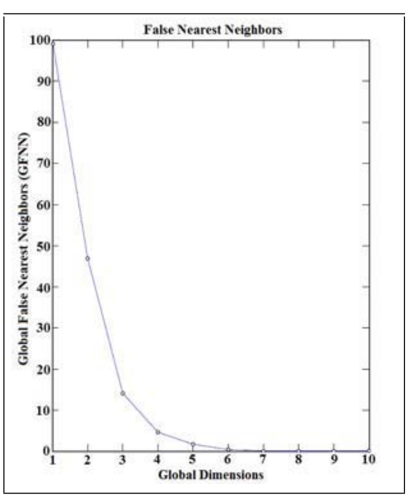


Figure 4: Global False Nearest Neighbors (GFNN) with Global Dimensions

The global dimension is chosen where the total percentage of false neighbors approaches zero, thus providing a suffcient number of coordinates to define the system state at all points in time, [17]. It can be suggested that it may be more appropriate to τ_w the reconstruction window, τ_w, rather than τ alone, in which τ_w and τ are interchanged as dictated by the particular context, as illustrated below: [18, 19, 20, 21]:

$$\tau_w = \tau(d_E - 1) \tag{6}$$

IV. Experimental Setup

Our rig is based on a radial cam with an oscillating roller-follower. A spring with the elastic constant is used to maintain the contact between the cam and the follower. Figure 5 shows the curve fitting of spring stiffness values.

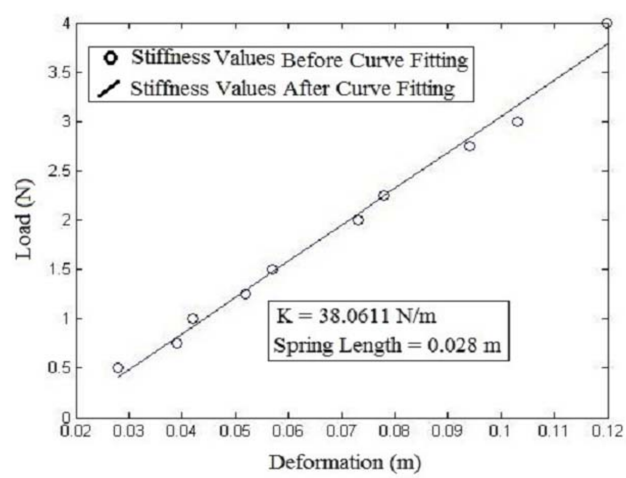


Figure 5: Load-Deflection Curve Fitting

The stiffness of the contact-retaining spring is determined to cause a minimum force pushing the follower system towards the cam. The system with follower's guide clearance C = 0.3 mm was used. The cam-follower mechanism has been manufactured by a 3D printing filament technique device. The mechanical device was shown to be appropriately coupled to electronic systems for the acquisition, storage and processing of experimental data, [10]. The main feature of the experimental set-up can be summarized as follows: (1) The cam motion was controlled by a brush-less motor driven through an embedded controller. The angular position of the cam and the driving motor were assumed to be identical. (2) The measures of the cam and the follower positions are obtained through high-resolution optical encoders (markers). The marker has been stick on the follower which has the coordinates (x: 0, y: 272 mm, z: 0). (3) The OPTOTRAK / 3020 used to capture the motion through an infrared 3-D camera. The signals are analyzed using MATLAB program. The experimental rig was depicted in Fig. 6.

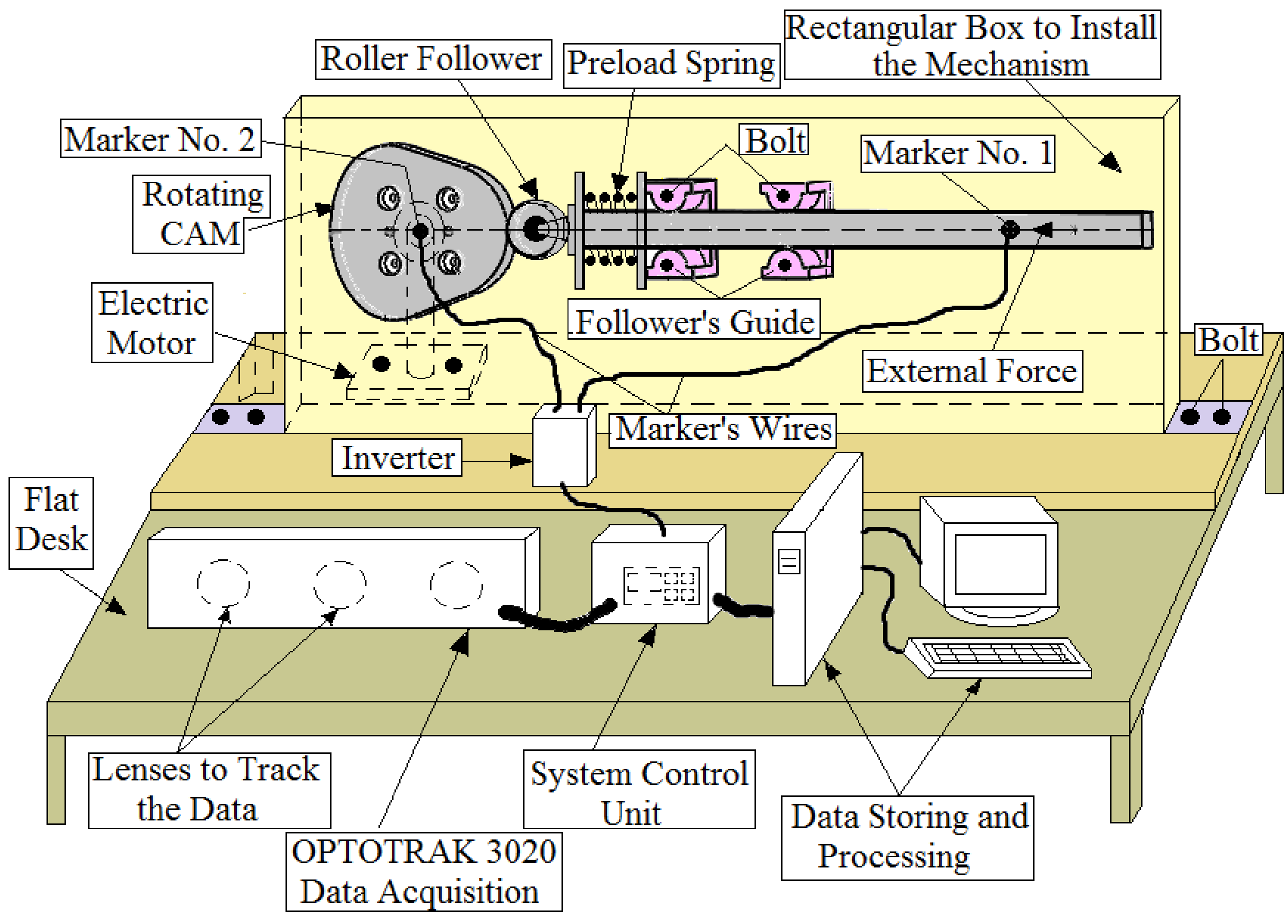


Figure 6: Experimental Rig Test

V. Finite-Time Lyapunov Exponent

Lyapunov exponents quantify the average exponential rate of divergence of neighboring trajectories in state space domain, and thus provide a direct measure of the sensitivity of the system to infinitesimal perturbations [15]. The maximum Lyapunov exponent (λ) can be defined by using the equation below:

$$d(t) = De^{\lambda t} \tag{7}$$

The Lyapunov exponent values were estimated from the slopes of linear fits to curves defined by:

$$y(i) = \frac{1}{\Delta t}\langle ln[d_j(i)]\rangle \tag{8}$$

The Rosenstein method [14] estimates the largest Lyapunov exponents of a reconstructed attractor. The input to the program is a scalar follower displacement along with several parameters such as time delay and embedding dimension. The basic principle of this algorithm is to calculate the diverging ratio between trajectories in the state space domain, [22, 23]. The largest Lyapunov exponent was estimated from best-fit linear slopes of these local divergence curves. The average local Lyapunov exponents determine the stability of the dynamic system using attractor trajectories. When the attractor is non-periodic, the trajectories diverge, on average, at an exponential rate characterized by the largest Lyapunov exponent [24]. The presence of a positive exponent is sufficient for diagnosing chaos and represents local instability in a particular direction. Larger values of Lyapunov exponents imply more divergence and variability of a system while smaller values reect less divergence and variability. On the other hand, the lower positive Lyapunov exponents imply less sensitivity to perturbations. [25].

VI. Results and Discussion

The verification of the follower linear displacement based on experiment and simulation techniques has been shown in Fig. 7. The simulation results were carried out using the y-direction because the simulation was obvious and clear. The verification was done by using N = 400 rpm of cam rotational speed. The system with follower's guide clearance C = 0.3 mm was used in the verification. In high-speed machinery, the jump is a situation where the cam and follower substantially scattered.

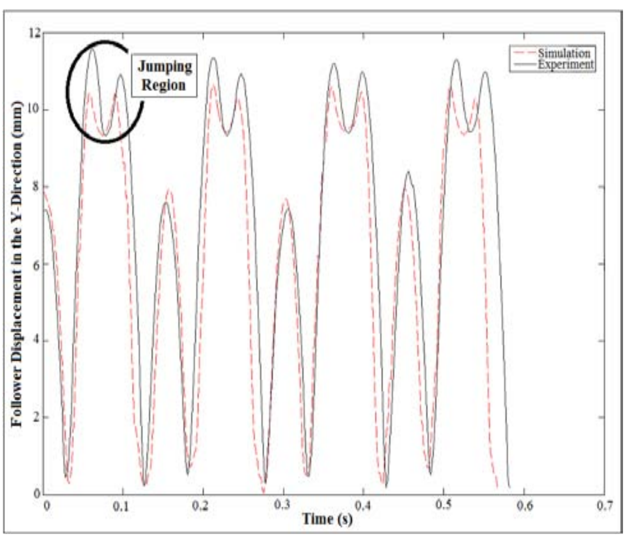


Figure 7: Follower Displacement in the Y-Direction

Table (2) shows the simulation of Lyapunov exponent values varying with cam rotational speeds and follower guides' clearances. It can be observed that the largest Lyapunov exponent values are extremely constant for cam rotational speed N = 200 rpm and N = 500 rpm. The system with lowest Lyapunov exponent gives indication of local dynamic stability. The system with largest Lyapunov exponent represents the dynamic instability. The system with follower guide's clearance C = 2 mm and cam rotational speed N = 300 rpm has largest Lyapunov exponent. The system with follower guide's clearance C = 1.5 mm and cam speeds N = 400 rpm represents the local dynamic stability.

Table 2: Lyapunov Exponent Values Varying with Cam Rotational Speeds and Clearances

Cam Speed (rpm)	Clearance (0.5mm)	Clearance (1 mn)	Clearance (1.5 mm)	Clearance (2 mm)
200	0.284	0.211	0.217	0.181
300	0.192	0.28	0.208	0.416
400	0.384	0.321	0.124	0.128
500	0.239	0.191	0.267	0.277
600	0.348	0.369	0.203	0.179
700	0.241	0.266	0.307	0.283
800	0.236	0.3	0.366	0.349

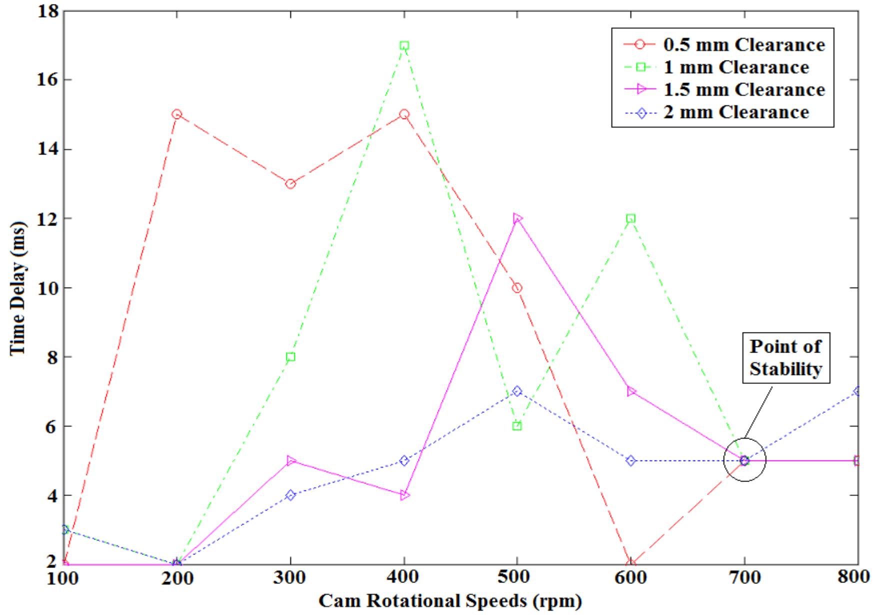
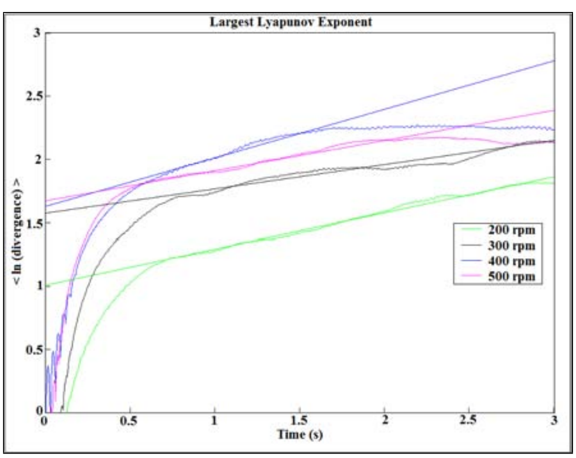
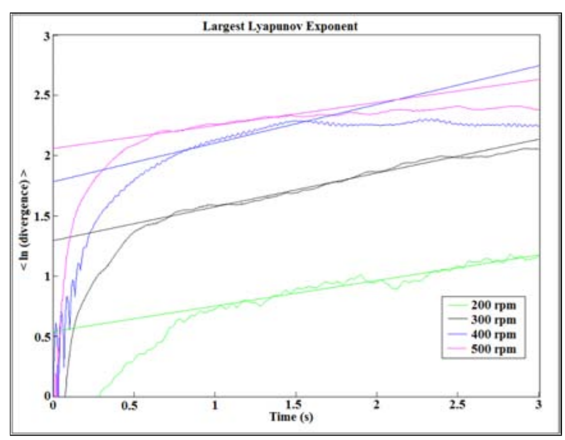


Figure 8: Illustrates the time delay variation with cam rotational speeds

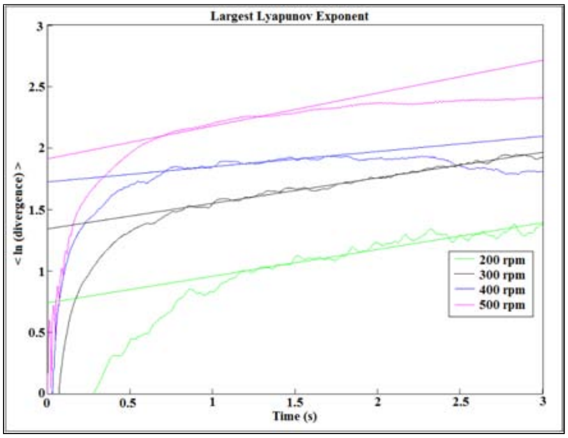
The (AMI) algorithm has been done to find the time delay of cam-follower mechanism. At cam rotational speed N = 700 rpm the time delay is constant for whole values of cam rotational speeds. Figures 9a, 9b, 9c, and 9d have been done by using the Rosenstein method. The average logarithmic divergence for curve fitting has been touched the curve of average logarithmic divergence without any oscillation specially in Fig. 9a. The logarithmic divergence curve has been different cam rotational speeds and different follower guides clearances were investigated. The curve represents the average logarithmic divergence for follower attractor trajectories. The straight line represents the line of curvetting of least-square method which is given large Lyapunov exponent. The straight line of oscillation as in Fig. 9c, and 9d in which represents local dynamic instability. Figure 9a indicates to local dynamic stability.



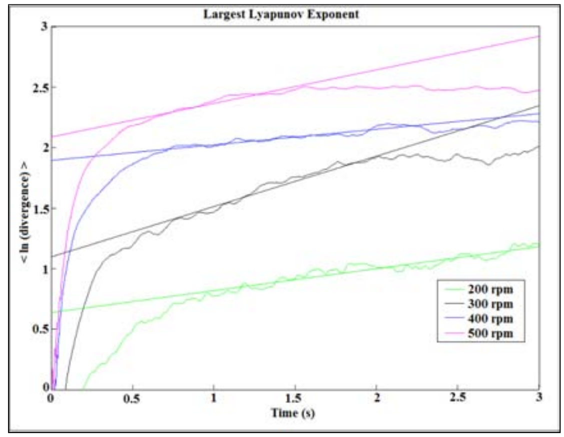
a) Average Logarithmic Divergence for Clearance C = 0.5 mm.



b) Average Logarithmic Divergence for Clearance C = 1 mm.



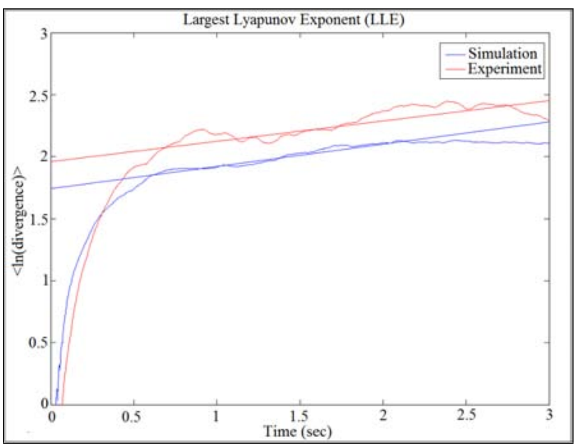
c) Average Logarithmic Divergence for Clearance C = 1.5 mm.



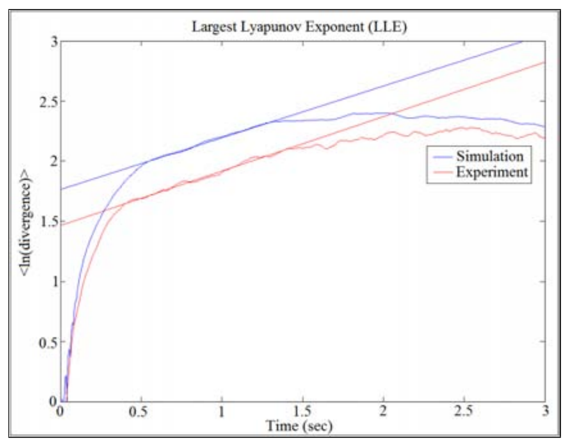
d) Average Logarithmic Divergence for Clearance C = 2 mm.

Figure 9: Average Logarithmic Divergence for Different Follower Guides' Clearances

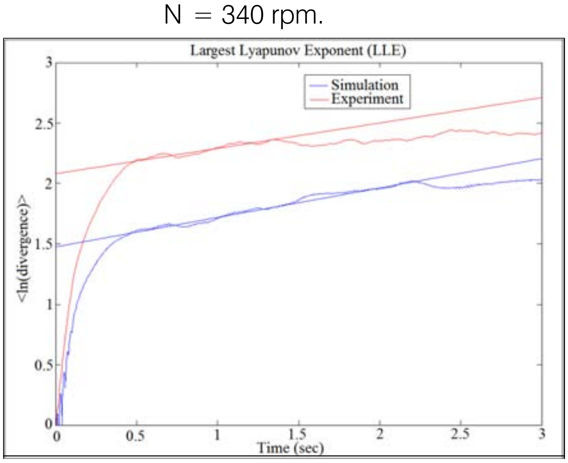
Figures 10a, 10b, 10c, and 10d show the logarithmic divergence verification of largest Lyapunov exponent. Clearance C = 0.3 mm was considered in the verification. It can be seen from these figures that the average logarithmic divergence curve has been of oscillation around the straight line of curve fitting Experimentally except in Figures 10b, and 10c. In the simulation analysis, the average logarithmic divergence curve is nearly tangent to the straight line of curve fitting.



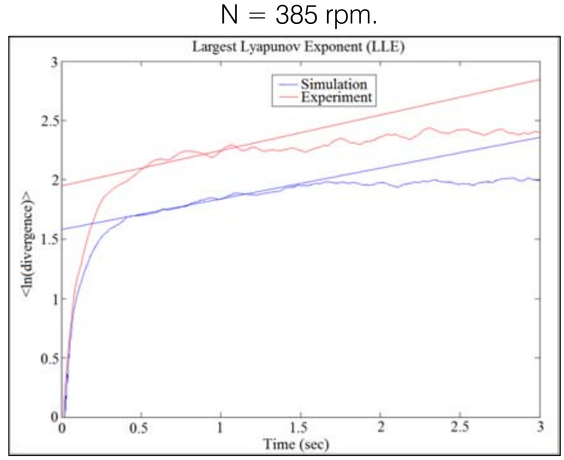
(a) Average Logarithmic Divergence Verification of N = 340 rpm.



(b) Average Logarithmic Divergence Verification of N = 385 rpm.



(c) Average Logarithmic Divergence Verification of N = 410 rpm.



(d) Average Logarithmic Divergence Verification of N = 423 rpm.

Figure 10: Average Logarithmic Divergence for Verification of Different Cam Rotational Speed.

Table (3) shows the large Lyapunov exponent values verification varying with cam rotational speeds. The system with followers guide clearance C = 0.3 mm was used in the verification. The system with cam speed N = 340 rpm and Lyapunov exponent equal to (0.18) represents local dynamic stability. The system with cam speed N = 385 rpm and Lyapunov exponent equal to (0.431) indicates local dynamic instability.

Table 3: Lyapunov Exponent Values Verification for Difierent Cam Rotational Speeds

Carm Speed (rpm)	Simulation	Experiment	Error %
340	0.18	0.164	8.88
385	0.431	0.454	5.06
410	0.244	0.210	13.93
423	0.26	0.299	13.04

Figure 11 illustrates the Largest Lyapunov Exponent verses with cam rotational speed for different follower guides clearances. The system with follower guides clearance C = 2 mm and N = 300 rpm has Lyapunov exponent equal to 0.42. The system with clearance C = 1.5 mm has Lyapunov exponent close to zero specially at N = 100 rpm.

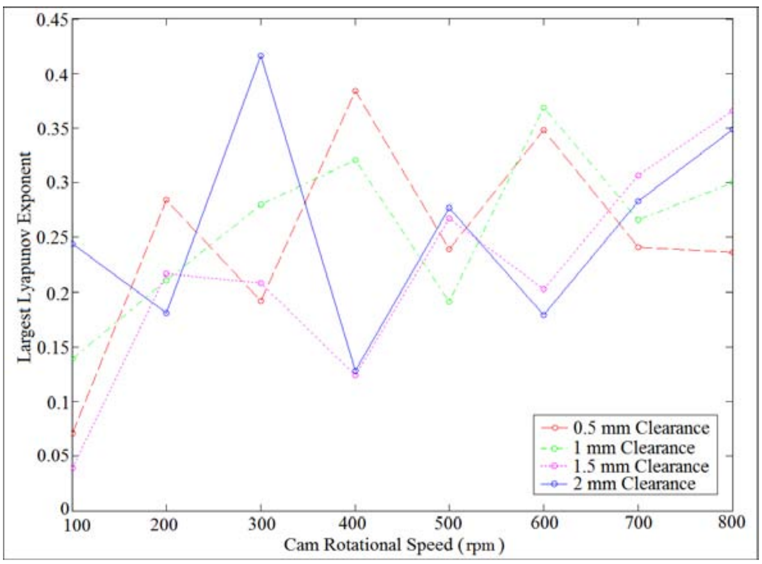


Figure 11: Largest Lyapunov Exponent Varying with Cam Rotational Speed and Different Follower Guides' Clearances

VII. Conclusions

This study analyze and discuss the largest Lyapunov exponent for the cam follower mechanism. Experimental part has been analyzed with data acquisition techniques using 3-D infrared system in order to measure the follower displacement. The numerical part has been done using Solidwork simulation. The system with lowest Lyapunov exponent gives indication of local dynamic stability. The system with largest Lyapunov exponent represents the dynamic instability.

The system with follower guide's clearance C = 2 mm and cam rotational speed N = 300 rpm has largest Lyapunov exponent. The system with follower guide's clearance C = 1.5 mm and cam speeds N = 400 rpm represents the local dynamic stability. The average logarithmic divergence curve has been oscillated around the straight line of curve fitting experimentally. In the simulation analysis, the average logarithmic divergence curve is nearly tangent to the straight line of curve fitting.

Numenculture

C: Follower guide's clearance.
D: Average displacement between trajectories at t=0.
F: External follower force.
Fc: Contact force between cam and follower.
K: Contact bodies stiffness.
N: Cam rotational speed.
n: Exponent.
τ: Lag or reconstruction time delay.
X (t): Original one-dimensional data.
y (i) : Curve fitting least square follower displacement data.
dE: Embedding dimension.
d (t) : Rate of change in the distance between nearest neighbors.
$d_j(i)$: Euclidean distance between the pair of nearest neighbors.
Δ: Follower linear displacement varying with time.
Δt: Discrete time steps.

δ: Penetration.
ς: Damping ratio.
τ : Delay parameter.
τ_w: Length of the interval spanned by the first and last delay coordinates.
λ : Lyapunov exponent.

Références

1. Y. Unlusoy, S. Tumer, Non -linear dynamic model and its solution for a high speed cam mechanism with coulomb friction, Journal of sound and vibration 169 (3) (1994) 395-407.
2. H. Hamidzadeh, M. Dehghani, Dynamic stability of flexible cam follower systems, Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics 213 (1) (1999) 45-52.
3. M. Tounsi, R. Hbaieb, F. Chaari, T. Fakhfakh, M. Haddar, Dynamic stability analysis of a flexible cam mechanism using a one-degree-of-freedom model, Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science 223 (5) (2009) 1057-1068.
4. L. Cveticanin, Stability of motion of the cam follower system, Mechanism and machine theory 42 (9) (2007) 1238-1250.
5. J. Guo, W. Zhang, X. Zhang, Y. Cao, Dynamic and exciting analysis with modal characteristics for valve train using a flexible model, Mechanism and Machine Theory 78 (2014) 158-176.
6. W. Hsu, A. Pisano, Modeling of a finger-follower cam system with verification in contact forces, Journal of Mechanical Design 118 (1) (1996) 132-137.
7. C. Chuang, Minimizing residual vibrations in high-speed cam-foilower systems over a range of speeds, Journal of Mechanical Design 117 (1995) 167-172
8. B. Fabien, R. Longman, F. Freudenstein, The design of high-speed dwell-rise-dwell cams using linear quadratic optimal control theory, Journal of Mechanical Design 116 (3) (1994) 867-874.
9. J. Jiang, Y. Iwai, H. Su, Minimizing and restricting vibrations in high-speed cam-follower systems over a range of speeds, Journal of Applied Mechanics 74 (6) (2007) 1157-1164.
10. R. Alzate, M. Di Bernardo, U. Montanaro, S. Santini, Experimental and numerical verification of bifurcations and chaos in cam-follower impacting systems, Nonlinear Dynamics 50 (3) (2007) 409-429.
11. H.-S. Yan, M.-C. Tsai, M.-H. Hsu, A variable-speed method for improving motion characteristics of cam-follower systems, Journal of Mechanical Design 118 (2) (1996) 250-258.
12. C. Bagci, S. Kurnool, Exact response analysis and dynamic design of cam-follower systems using laplace transforms, Journal of Mechanical Design 119 (3) (1997) 359-369.
13. D. Planchard, Solidworks 2017 Reference Guide, SDC Publications, (2017).
14. M. T. Rosenstein, J. J. Collins, C. J. De Luca, A practical method for calculating largest lyapunov exponents from small data sets, Physica D:Nonlinear Phenomena 65 (1) (1993) 117-134.
15. J. B. Dingwell, J. P. Cusumano, Nonlinear time series analysis of normal and pathological human walking, Chaos: An Interdisciplinary Journal of Nonlinear Science 10 (4) (2000) 848-863.
16. M. T. Rosenstein, J. J. Collins, C. J. De Luca, Reconstruction expansion as a geometry-based framework for choosing proper delay times, Physica D: Nonlinear Phenomena 73 (1) (1994) 82-98.
17. J. Dingwell, J. Cusumano, P. Cavanagh, D. Sternad, Local dynamic stability versus kinematic variability of continuous overground and treadmill walking, Journal of biomechanical engineering 123 (1) (2001) 27-32.
18. D. S. Broomhead, G. P. King, Extracting qualitative dynamics from experimental data, Physica D: Nonlinear Phenomena 20 (2-3) (1986) 217-236.
19. Mees, P. Rapp, L. Jennings, Singular-value decomposition and embedding dimension, Physical Review A 36 (1) (1987) 340.
20. M. Albano, J. Muench, C. Schwartz, A. Mees, P. Rapp, Singular-value decomposition and the grassberger-procaccia algorithm, Physical Review A 38 (6) (1988) 3017.
21. J. Martinerie, A. M. Albano, A. Mees, P. Rapp, Mutual information, strange attractors, and the optimal estimation of dimension, Physical Review A 45 (10) (1992) 7058.
22. T. Schreiber, A. Schmitz, Surrogate time series, Physica D: Nonlinear Phenomena 142 (3) (2000) 346-382.
23. R. Hegger and H. Kantz, Practical implementation of nonlinear time series methods: The TISEAN package, Chaos: An Interdisciplinary Journal of Nonlinear Science9 (2), (1999), 413-435.
24. J. Eckmann, D. Ruelle, Ergodic theory of chaos and strange attractors, World Scientific Series on Nonlinear Science Series A 16 (1995) 365-404.
25. K. Son, J. Park, S. Park, Variability analysis of lower extremity joint kinematics during walking in healthy young adults, Medical engineering & physics 31 (7) (2009) 784-792.

Global Journals Guidelines Handbook 2018

www.GlobalJournals.org

Fellows

FELLOW OF ASSOCIATION OF RESEARCH SOCIETY IN ENGINEERING (FARSE)

Global Journals Incorporate (USA) is accredited by Open Association of Research Society (OARS), U.S.A and in turn, awards "FARSE" title to individuals. The 'FARSE' title is accorded to a selected professional after the approval of the Editor-in-Chief /Editorial Board Members/Dean.

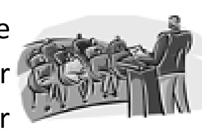
- The "FARSE" is a dignified title which is accorded to a person's name viz. Dr. John E. Hall, Ph.D., FARSE or William Walldroff, M.S., FARSE.

FARSE accrediting is an honor. It authenticates your research activities. After recognition as FARSE, you can add 'FARSE' title with your name as you use this recognition as additional suffix to your status. This will definitely enhance and add more value and repute to your name. You may use it on your professional Counseling Materials such as CV, Resume, and Visiting Card etc.

The following benefits can be availed by you only for next three years from the date of certification:

FARSE designated members are entitled to avail a 40% discount while publishing their research papers (of a single author) with Global Journals Incorporation (USA), if the same is accepted by Editorial Board/Peer Reviewers. If you are a main author or co-author in case of multiple authors, you will be entitled to avail discount of 10%.

Once FARSE title is accorded, the Fellow is authorized to organize a symposium/seminar/conference on behalf of Global Journal Incorporation (USA).The Fellow can also participate in conference/seminar/symposium organized by another institution as representative of Global Journal. In both the cases, it is mandatory for him to discuss with us and obtain our consent.

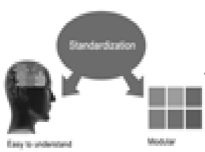


You may join as member of the Editorial Board of Global Journals Incorporation (USA) after successful completion of three years as Fellow and as Peer Reviewer. In addition, it is also desirable that you should organize seminar/symposium/conference at least once.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

The FARSE can go through standards of OARS. You can also play vital role if you have any suggestions so that proper amendment can take place to improve the same for the benefit of entire research community.

As FARSE, you will be given a renowned, secure and free professional email address with 100 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders,Auto-Responders, Email Delivery Route tracing, etc.



The FARSE will be eligible for a free application of standardization of their researches. Standardization of research will be subject to acceptability within stipulated norms as the next step after publishing in a journal. We shall depute a team of specialized research professionals who will render their services for elevating your researches to next higher level, which is worldwide open standardization.

The FARSE member can apply for grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A. Once you are designated as FARSE, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria. After certification of all your credentials by OARS, they will be published on your Fellow Profile link on website https://associationofresearch.org which will be helpful to upgrade the dignity.

The FARSE members can avail the benefits of free research podcasting in Global Research Radio with their research documents. After publishing the work, (including published elsewhere worldwide with proper authorization) you can upload your research paper with your recorded voice or you can utilize chargeable services of our professional RJs to record your paper in their voice on request.

The FARSE member also entitled to get the benefits of free research podcasting of their research documents through video clips. We can also streamline your conference videos and display your slides/ online slides and online research video clips at reasonable charges, on request.

The FARSE is eligible to earn from sales proceeds of his/her researches/reference/review Books or literature, while publishing with Global Journals. The FARSE can decide whether he/she would like to publish his/her research in a closed manner. In this case, whenever readers purchase that individual research paper for reading, maximum 60% of its profit earned as royalty by Global Journals, will be credited to his/her bank account. The entire entitled amount will be credited to his/her bank account exceeding limit of minimum fixed balance. There is no minimum time limit for collection. The FARSE member can decide its price and we can help in making the right decision.

The FARSE member is eligible to join as a paid peer reviewer at Global Journals Incorporation (USA) and can get remuneration of 15% of author fees, taken from the author of a respective paper. After reviewing 5 or more papers you can request to transfer the amount to your bank account.

MEMBER OF ASSOCIATION OF RESEARCH SOCIETY IN ENGINEERING (MARSE)

The ' MARSE ' title is accorded to a selected professional after the approval of the Editor-in-Chief / Editorial Board Members/Dean.

The “MARSE” is a dignified ornament which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., MARSE or William Walldroff, M.S., MARSE.

MARSE accrediting is an honor. It authenticates your research activities. After becoming MARSE, you can add 'MARSE' title with your name as you use this recognition as additional suffix to your status. This will definitely enhance and add more value and repute to your name. You may use it on your professional Counseling Materials such as CV, Resume, Visiting Card and Name Plate etc.

The following benefitscan be availed by you only for next three years from the date of certification.

MARSE designated members are entitled to avail a 25% discount while publishing their research papers (of a single author) in Global Journals Inc., if the same is accepted by our Editorial Board and Peer Reviewers. If you are a main author or co-author of a group of authors, you will get discount of 10%.

As MARSE, you will be given a renowned, secure and free professional email address with 30 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders,Auto-Responders, Email Delivery Route tracing, etc.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

The MARSE member can apply for approval, grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A.

Once you are designated as MARSE, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria.

It is mandatory to read all terms and conditions carefully.

Institutional Fellow of Open Association of Research Society (USA)-OARS (USA)

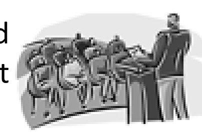
Global Journals Incorporation (USA) is accredited by Open Association of Research Society, U.S.A (OARS) and in turn, affiliates research institutions as "Institutional Fellow of Open Association of Research Society" (IFOARS).

The "FARSC" is a dignified title which is accorded to a person's name viz. Dr. John E. Hall, Ph.D., FARSC or William Walldroff, M.S., FARSC.

The IFOARS institution is entitled to form a Board comprised of one Chairperson and three to five board members preferably from different streams. The Board will be recognized as "Institutional Board of Open Association of Research Society"-(IBOARS).

The Institute will be entitled to following benefits:

The IBOARS can initially review research papers of their institute and recommend them to publish with respective journal of Global Journals. It can also review the papers of other institutions after obtaining our consent. The second review will be done by peer reviewer of Global Journals Incorporation (USA) The Board is at liberty to appoint a peer reviewer with the approval of chairperson after consulting us.
The author fees of such paper may be waived off up to 40%.



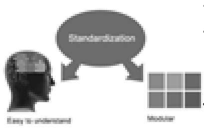
The Global Journals Incorporation (USA) at its discretion can also refer double blind peer reviewed paper at their end to the board for the verification and to get recommendation for final stage of acceptance of publication.

The IBOARS can organize symposium/seminar/conference in their country on behalf of Global Journals Incorporation (USA)-OARS (USA). The terms and conditions can be discussed separately.

The Board can also play vital role by exploring and giving valuable suggestions regarding the Standards of "Open Association of Research Society, U.S.A (OARS)" so that proper amendment can take place for the benefit of entire research community. We shall provide details of particular standard only on receipt of request from the Board.

The board members can also join us as Individual Fellow with 40% discount on total fees applicable to Individual Fellow. They will be entitled to avail all the benefits as declared. Please visit Individual Fellow-sub menu of GlobalJournals.org to have more relevant details.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time. This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.



After nomination of your institution as "Institutional Fellow" and constantly functioning successfully for one year, we can consider giving recognition to your institute to function as Regional/Zonal office on our behalf.

The board can also take up the additional allied activities for betterment after our consultation.

The following entitlements are applicable to individual Fellows:

Open Association of Research Society, U.S.A (OARS) By-laws states that an individual Fellow may use the designations as applicable, or the corresponding initials. The Credentials of individual Fellow and Associate designations signify that the individual has gained knowledge of the fundamental concepts. One is magnanimous and proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice.

Open Association of Research Society (US)/ Global Journals Incorporation (USA), as described in Corporate Statements, are educational, research publishing and professional membership organizations. Achieving our individual Fellow or Associate status is based mainly on meeting stated educational research requirements.

Disbursement of 40% Royalty earned through Global Journals : Researcher = 50%, Peer Reviewer = 37.50%, Institution = 12.50% E.g. Out of 40%, the 20% benefit should be passed on to researcher, 15 % benefit towards remuneration should be given to a reviewer and remaining 5% is to be retained by the institution.

We shall provide print version of 12 issues of any three journals [as per your requirement] out of our 38 journals worth $ 2376 USD.

Other:

The individual Fellow and Associate designations accredited by Open Association of Research Society (US) credentials signify guarantees following achievements:

- The professional accredited with Fellow honor, is entitled to various benefits viz. name, fame, honor, regular flow of income, secured bright future, social status etc.

- In addition to above, if one is single author, then entitled to 40% discount on publishing research paper and can get 10%discount if one is co-author or main author among group of authors.
- The Fellow can organize symposium/seminar/conference on behalf of Global Journals Incorporation (USA) and he/she can also attend the same organized by other institutes on behalf of Global Journals.
- The Fellow can become member of Editorial Board Member after completing 3yrs.
- The Fellow can earn 60% of sales proceeds from the sale of reference/review books/literature/publishing of research paper.
- Fellow can also join as paid peer reviewer and earn 15% remuneration of author charges and can also get an opportunity to join as member of the Editorial Board of Global Journals Incorporation (USA)
- • This individual has learned the basic methods of applying those concepts and techniques to common challenging situations. This individual has further demonstrated an in–depth understanding of the application of suitable techniques to a particular area of research practice.

Note :

〃

- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
- In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
- In case of "Difference of Opinion [if any]" among the Board members, our decision will be final and binding to everyone. 〃

Preferred Author Guidelines

We accept the manuscript submissions in any standard (generic) format.

We typeset manuscripts using advanced typesetting tools like Adobe In Design, CorelDraw, TeXnicCenter, and TeXStudio. We usually recommend authors submit their research using any standard format they are comfortable with, and let Global Journals do the rest.

Alternatively, you can download our basic template from https://globaljournals.org/Template.zip

Authors should submit their complete paper/article, including text illustrations, graphics, conclusions, artwork, and tables. Authors who are not able to submit manuscript using the form above can email the manuscript department at submit@globaljournals.org or get in touch with chiefeditor@globaljournals.org if they wish to send the abstract before submission.

Before and during Submission

Authors must ensure the information provided during the submission of a paper is authentic. Please go through the following checklist before submitting:

1. Authors must go through the complete author guideline and understand and *agree to Global Journals' ethics and code of conduct,* along with author responsibilities.
2. Authors must accept the privacy policy, terms, and conditions of Global Journals.
3. Ensure corresponding author's email address and postal address are accurate and reachable.
4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s') names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
6. Proper permissions must be acquired for the use of any copyrighted material.
7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

Declaration of Conflicts of Interest

It is required for authors to declare all financial, institutional, and personal relationships with other individuals and organizations that could influence (bias) their research.

Policy on Plagiarism

Plagiarism is not acceptable in Global Journals submissions at all.

Plagiarized content will not be considered for publication. We reserve the right to inform authors' institutions about plagiarism detected either before or after publication. If plagiarism is identified, we will follow COPE guidelines:

Authors are solely responsible for all the plagiarism that is found. The author must not fabricate, falsify or plagiarize existing research data. The following, if copied, will be considered plagiarism:

- Words (language)
- Ideas
- Findings
- Writings
- Diagrams
- Graphs
- Illustrations
- Lectures

- Printed material
- Graphic representations
- Computer programs
- Electronic material
- Any other original work

Authorship Policies

Global Journals follows the definition of authorship set up by the Open Association of Research Society, USA. According to its guidelines, authorship criteria must be based on:

1. Substantial contributions to the conception and acquisition of data, analysis, and interpretation of findings.
2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

Changes in Authorship

The corresponding author should mention the name and complete details of all co-authors during submission and in manuscript. We support addition, rearrangement, manipulation, and deletions in authors list till the early view publication of the journal. We expect that corresponding author will notify all co-authors of submission. We follow COPE guidelines for changes in authorship.

Copyright

During submission of the manuscript, the author is confirming an exclusive license agreement with Global Journals which gives Global Journals the authority to reproduce, reuse, and republish authors' research. We also believe in flexible copyright terms where copyright may remain with authors/employers/institutions as well. Contact your editor after acceptance to choose your copyright policy. You may follow this form for copyright transfers.

Appealing Decisions

Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

Declaration of funding sources

Global Journals is in partnership with various universities, laboratories, and other institutions worldwide in the research domain. Authors are requested to disclose their source of funding during every stage of their research, such as making analysis, performing laboratory operations, computing data, and using institutional resources, from writing an article to its submission. This will also help authors to get reimbursements by requesting an open access publication letter from Global Journals and submitting to the respective funding source.

Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, “What words would a source have to include to be truly valuable in a research paper?” Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

Index

save our planet

Global Journal of Researches in Engineering

Visit us on the Web at www.GlobalJournals.org | www.EngineeringResearch.org
or email us at helpdesk@globaljournals.org

ISSN 9755861