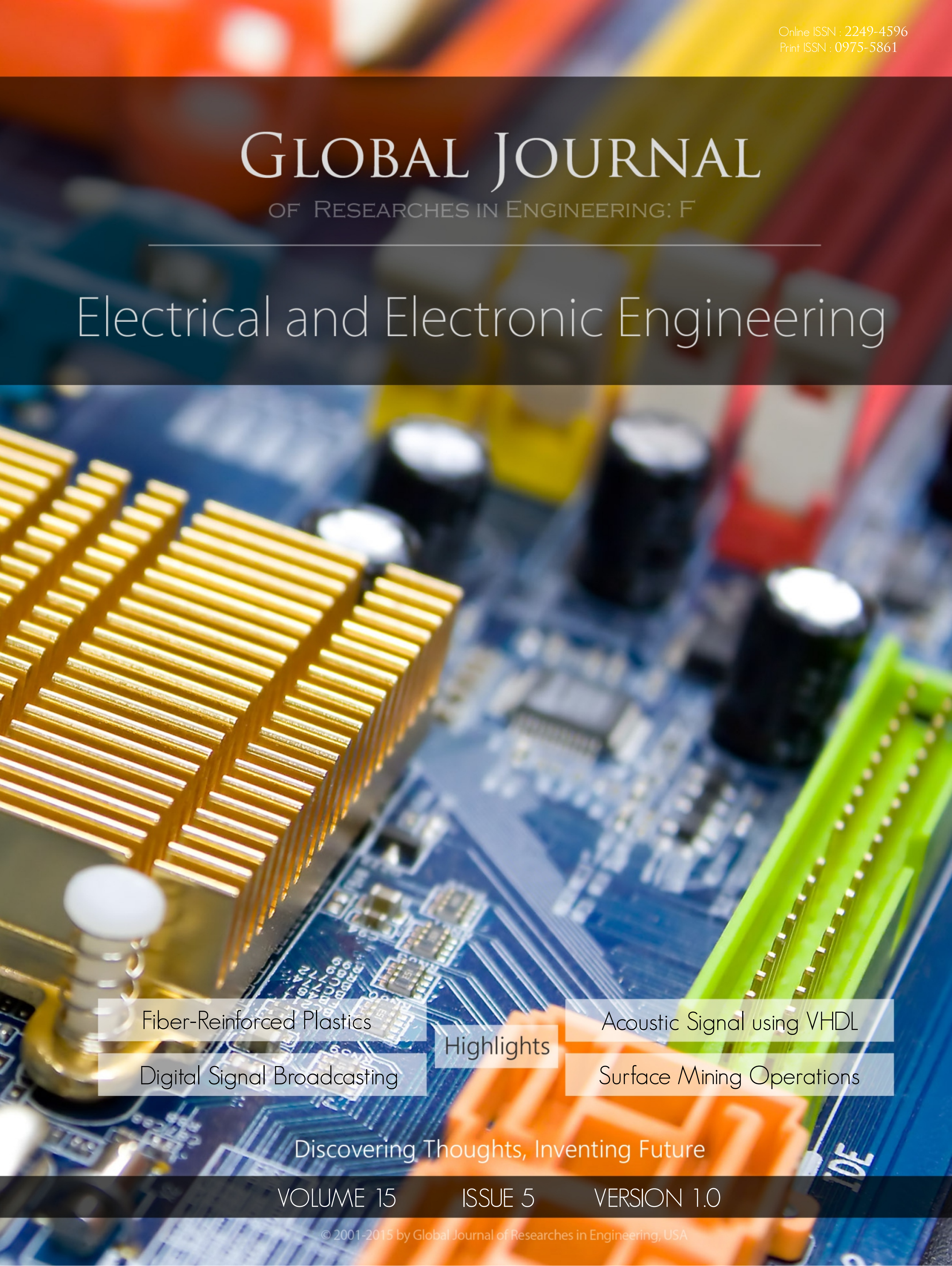

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Electrical and Electronic Engineering

Highlights

Fiber-Reinforced Plastics

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Acoustic Signal using VHDL

Surface Mining Operations

Discovering Thoughts, Inventing Future

VOLUME 15 ISSUE 5 VERSION 1.0

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By I.S.N.V.R. Prasanth , Dr. D. V. Ravishankar & Dr. Manzoor Hussain

Bharat Institute of Engineering & technology, India

Abstract- Some invariable situations where component to be joined even though machining is not advisable for composites. But special situations here present work aimed at identifying better machining process parameters to arrive at defect free machined surfaces. In general laminated composite materials are machined at very high speed to generate a defect free machined surface. The precise measurement of cutting forces is very essential to know the influence of cutting forces of the work piece. In this connection precision machining is needed the present research work deals experimentations performed with two different mill tools and varieties of tool signatures are carefully analyzed with the mill tool dynamometer. The experimental layout was designed based on the 2^k factorial techniques and analysis of variance (ANOVA) was performed to identify the effect of cutting parameters on surface finish and cutting forces are developed by using multiple regression analysis.

Keywords: universal milling machine, cutting force, specially designed carbide tipped end mill tool, solid carbide end mill tool, 2^k factorial techniques.

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MILLINGOFGLASSFIBER-REINFORCEDPLASTICSANDINFLUENCEOFCUTTINGPROCESSPARAMETERSONCUTTINGFORCES

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I.S.N.V.R. Prasanth [α], Dr. D. V. Ravishankar [σ] & Dr. Manzoor Hussain [ρ]

Abstract- Some invariable situations where component to be joined even though machining is not advisable for composites. But special situations here present work aimed at identifying better machining process parameters to arrive at defect free machined surfaces. In general laminated composite materials are machined at very high speed to generate a defect free machined surface. The precise measurement of cutting forces is very essential to know the influence of cutting forces of the work piece. In this connection precision machining is needed the present research work deals experimentations performed with two different mill tools and varieties of tool signatures are carefully analyzed with the mill tool dynamometer. The experimental layout was designed based on the 2^k factorial techniques and analysis of variance (ANOVA) was performed to identify the effect of cutting parameters on surface finish and cutting forces are developed by using multiple regression analysis. By using mathematical model with 90% confidence level the effects of various process parameters on end milling was studied. Finally, the ranges for best cutting process parameters and model equations to predict the cutting force components are proposed.

Keywords: universal milling machine, cutting force, specially designed carbide tipped end mill tool, solid carbide end mill tool, 2^k factorial techniques.

I. Introduction

Milling is most commonly used machining operation in fabrication of aerospace and automobile parts of fiber reinforced plastics, milling of composites rather difficult task owing due to heterogeneity of material and anisotropic behavior. Some of the problems which will raised after machining of composites even taking at most precautions for good surface finish and defect free operations. Generally any defects influenced in milling process due to characteristics of material, cutting forces and cutting process parameters. In this connection research and development have to be carried out through design of experiments to get a good results to minimize the power consumption and delamination. The users of GFRP are facing the difficulties when machining it, because basic knowledge and experience needed for conventional materials cannot be applaid for such new innovative materials whose ability to machine is different from that of conventional material (MONTGOMERY 1991). Thus it is desirable to investigate the behavior of FRPs during machining process. Bhatnagar et ai (1995) studied how the fiber orientation influence both the quality of machined surfaces and tool wear rate. The machinability of composites are influenced by the type of fiber inserted in the composites, and especially by mechanical properties. Palanikumar et al. (2006) studied the effect of cutting parameters on surface roughness on machining of GFRP composites by PCD tool by developing a second order model for predicting the surface roughness average. Palanikumar et al. (2008) developed a procedure to optimizing the factors choosing to attain minimum surface roughness by incorporating response table and graph, normal plot, interaction plots, and analysis of variance technique. Davim et al (2004) examined cutting speed and feed rate as input parameters and surface roughness and delamination as output parameters. K10 carbide tools were used for milling process.

II. Experimental Procedure and Schematic of Machining

a) Experimental Procedure

The experiments has been conducted to evaluate the influence of input parameters; speed, feed and depth of cut on cutting force for two different tools. The range of parameters investigated; speed of 961 rpm and 1950rpm, feed rate 25mm/min and 50mm/min and depth of cut 3mm and 5mm. The design of matrix for experimental runs is shown in table 2 and 5 for the two tools Experiments has been conducted as per the design matrix and the response, cutting force are measured with help of mill tool dynamometer.

b) Schematic of machining

The work piece is used for present work is Glass fiber reinforced polymer composite fabricated by Hand lay up method, 40 % uni-directional fiber and 60 %of polyester resin. The dimensions of work piece are 100mmx100mmx10mm. In this study, the experiments are carried out on a conventional milling machine incorporated by high speed spindle motor 10Hp to

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perform slots on work pieces by Specially designed two flute carbide tipped end mill tool and k- 10 Solid carbide end mill tool. All the process parameters are regulated in this experiment. Each experiment were conducted three times, use the average values from them, the cutting force readings are taken from all level of experiments by mill tool dynamometer from data analog output lap top set up.

III. Design of Experiment

A factorial technique is studying each factors from the experiments with effect of cutting process parameters on response which is selected from the experiments runs. The main factor can be estimated but may be confounded with two factor interactions. The number of passes required by partial 2^k factorial design increase geometrically as K is increased and the larger number of trials called for is primarily to provide estimates of the increasing number of higher order interactions, which are most likely do not exist. Where k is number of input parameters.

a) *Exprimental Procedure as Per Taguchi Method (ANOVA) Factorial technique*

Experimental work was conducted on Universal milling machine, uni-directional glass fiber reinforced composite choosen as work piece material, specially designed Carbide tipped end mill tool & solid carbide K-10 end mill tools are choosen as cutting tool materials. Machining has been done as per the design matrix. In present study influence of process parameters on cutting forces are taken apart from various parameters. Hence experimentation is performed by minimum and maximum values of speed, feed and depth of cut.

Table 1 : Working limits of milling parameters

Working limits of milling parameters	Speed (rpm) A	Feed (mm/min), B	Depth of cut (mm), c
Maximum value	1950 (+)	50 (+)	5 (+)
Minimum value	961 (-)	25 (-)	3 (-)

b) *Estimated of Regression Coefficients*

The regression coefficients are calculated by using fallowing formula based on method of least squares.

Bj = xjiyiN Where: J = 0, 1, 2…k, Yi=Average

N = Number of experimental trails, X = Number of columns of the designed matrix, Xi= value of a factor or interaction in coded form. A matrix designed to apply the above formula for the calculation of regression co-efficient of the model is given in tables. Because of the orthogonal property of the design, the estimated coefficients are un correlate with one another. Since the method of least squares has been used to estimate the property of minimum variance. All the regression coefficients of the model are expressed by the above expression. The response parameters are estimated are also by taking standard Fishers ratio table. In the present case the tabulated value of F-ratio was found out as follows: $F_{ratio}=2x(S^2_{ad}/S^2_{y})$ Where, S^2_{ad}= Variance of adequacy or residual variance S^2y=Variance of optimization parameter of variance of reproducibility. The variance of adequacy was calculated by $S^2_{ad}=2(y_{avg} - y_{pre})^2$ /DOF Where y_{avg}=Value of response predicted. DOF=Degree of freedom and is equal to (n-(K+1), N = No of experimental trials, K =No. of independent variables, $S^2_{y}=2\ (y_1\text{-}y_{avg})^2$/DOF Y_{avg}=average of response observed, Y_1=other of the values of response parameter, DOF=Degree of freedom is equal to the number of experimental runs. The values are predicted by this model were also checked by actually conducting experiments by keeping the value of the process parameter at some values other than those used for developing the models but within the zone and the results obtained were found satisfactory. The comparison of two different tools are also predicted and then these models were used, represented by using the graphs and analyzing the results as shown from comparative table also.

IV. Results and Discussion

Table 1 : Calculation of experimental values for special carbide end mill tool

EXP.	N	f	d	F	F^2
1	+	+	+	1.91	3.6481
2	+	+	+	1.91	3.6481
3	+	+	-	1.2	1.44
4	+	-	-	0.5	0.25
5	+	-	-	1.82	3.3124
6	+	-	+	1.62	2.6244
7	+	-	+	0.4	0.16
8	+	+	-	2.1	4.41

Table 2 : Design matrix for cutting force of GFRP by special carbide end mill tool

EXP.	K	A	B	C	AB	BC	AC	ABC
1	+	+	+	+	+	+	+	+
2	+	+	+	-	+	-	-	-
3	+	+	-	-	-	+	-	+
4	+	-	-	-	+	+	+	-
5	+	-	-	+	+	-	-	+
6	+	-	+	+	-	+	-	-
7	+	-	+	-	-	-	+	+
8	+	+	-	+	-	-	+	-

Table 3 : Fishers values for cutting force of GFRP by special carbide end mill tool

K	RC	SS	DOF	FR
A	0.3475	0.4683	1	0.27
B	0.03	0.0036	1	0.0021
C	0.43	0.7396	1	0.435
AB	0.1025	0.042	1	0.024
BC	-0.125	0.0625	1	0.0367
AC	-0.08	0.0256	1	0.015
ABC	-0.1	0.04	1	0.23
SSR	1.4	7		
SST	3.07	15		
SSE	1.7	8		

Table 4 : Calculation of experimental values for solid carbide K-10 end mill tool

EXP NO	N	f	d	F	F^2
1	+	+	+	2.816	7.92
2	+	+	+	2.5	625
3	+	+	-	2.5	6.25
4	+	-	-	4.7	22.09
5	+	-	-	3	9
6	+	-	+	2.2	4.84
7	+	-	+	0.7	0.49
8	+	+	-	3.7	13.69

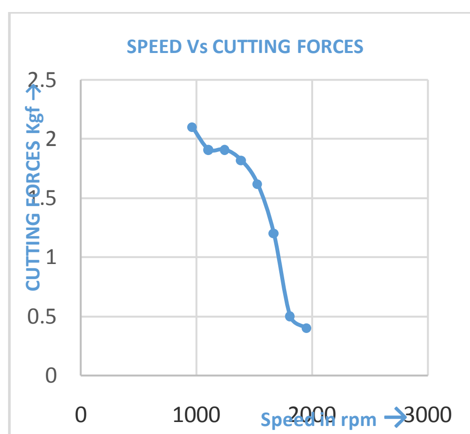
Table 5 : Design matrix for cutting force of GFRP by solid k 10 carbide tool

EXP.	K	A	B	C	AB	BC	AC	ABC
1	+	+	+	+	+	+	+	+
2	+	+	+	-	+	-	-	-
3	+	+	-	-	-	+	-	+
4	+	-	-	-	+	+	+	-
5	+	-	-	+	+	-	-	+
6	+	-	+	+	-	+	-	-
7	+	-	+	-	-	-	+	+
8	+	+	-	+	-	-	+	-

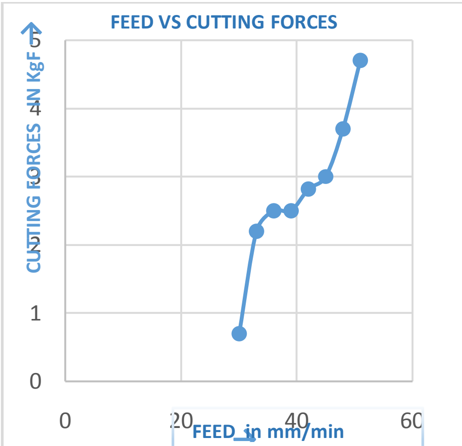
Table 6 : Fishers values for cutting force of GFRP by solid carbide K-10 end mill tool

Where, N=Speed, f=Feed, d=Depth of cut, RC=Regression coefficients, FR=Fishers ratio

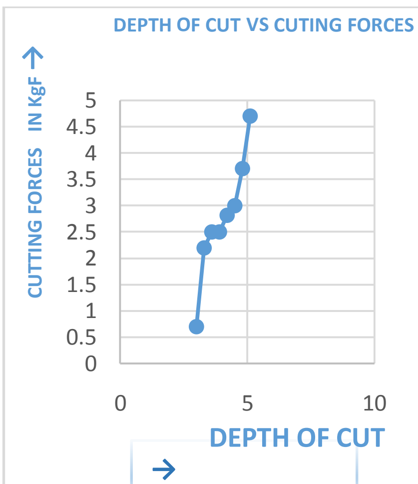
K	RC	SS	DOF	FR
A	0.1145	0.052	1	0.009
B	-0.71	2.01	1	0.36
C	0.164	0.108	1	0.02
AB	0.49	0.108	1	0.12
BC	0.29	0.36	1	0.064
AC	0.215	0.184	1	0.033
ABC	-0.51	1.04	1	0.184
SSR	3.71	7		
SST	9.4	15		
SSE	5.65	8		



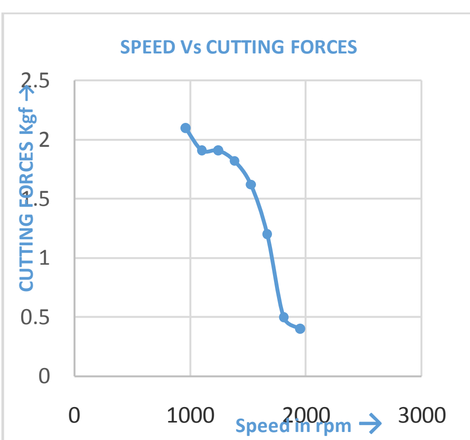
Graph 1 : Showing Variation of Cutting Force with Speed By special Carbide tipped end mill tool



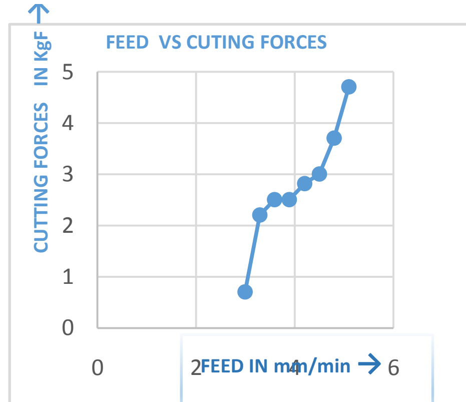
Graph 2 : Showing Variation of Cutting Force with Feed By special Carbide tipped end mill tool



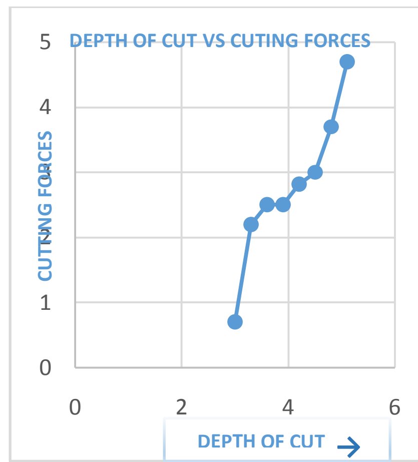
Graph 3 : Showing Variation of Cutting Force with Depth of cut By special Carbide tipped end mill tool



Graph 4 : Showing Variation of Cutting Force with Speed By special Carbide K-10 end mill tool



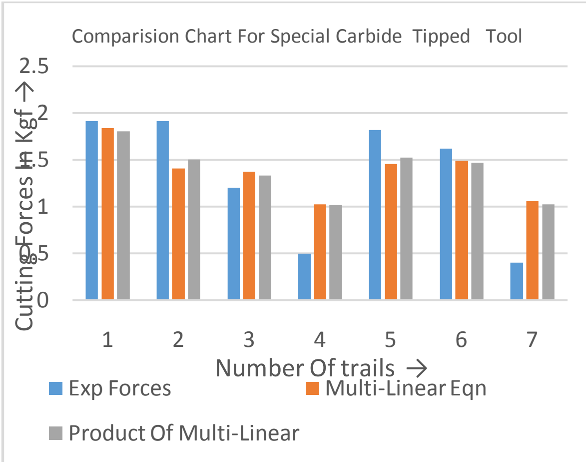
Graph 5 : Showing Variation of Cutting Force with Feed By Solid Carbide K-10 end mill tool



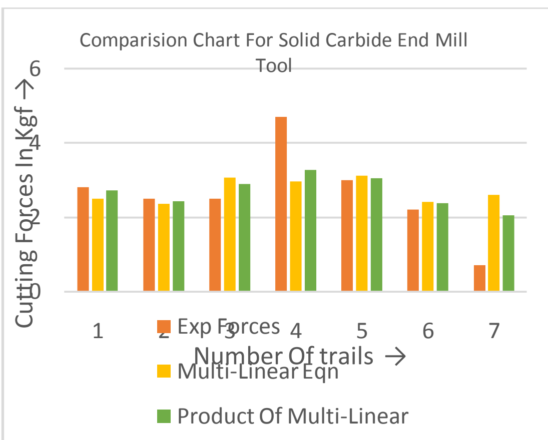
Graph 6 : Showing Variation of Cutting Force with Depth of cut By Solid Carbide K-10 end mill tool

a) Variation of Process parameters with cutting Force

The effect of machining parameters (speed, feed and depth of cut) on cutting forces is presented in following Fig. It is understood that Cutting forces increases with feed keeping other parameters constant,Cutting forces decreases with spindle speed keeping other parameters constant, Cutting forces increases with spindle speed keeping other parameters constant.



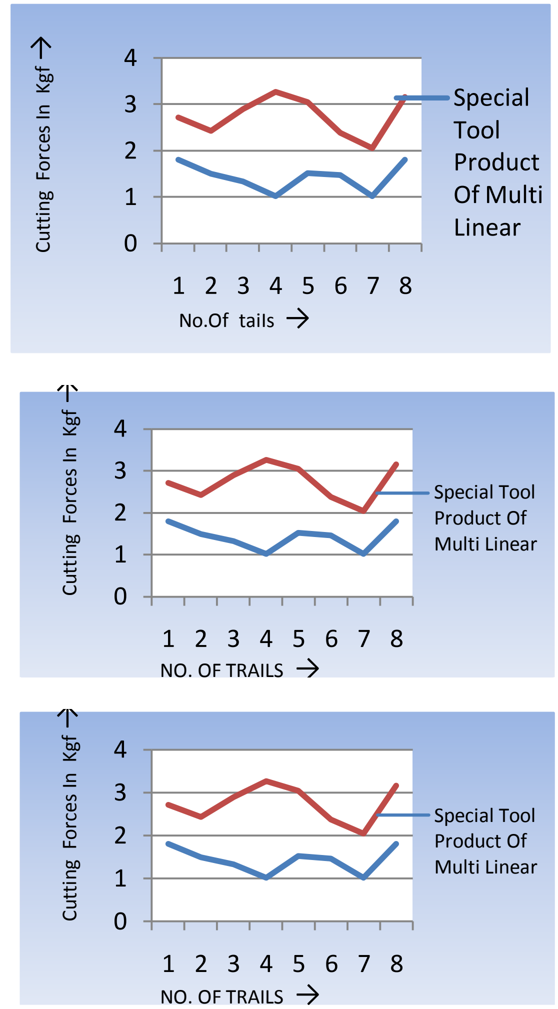
Graph 7 : Comparison of Cutting Forces for Experimental Values Of UD-GFRP By Solid K-10 Carbide mill tool



Graph 8 : Comparison of Cutting Forces for Experimental Values of special Carbide end mill tool

Table 8 : Comparison table for Cutting Force Values of Two different tools

With Special Carbide End Mill Tool			With Carbide k-10 End Mill Tool		
Resultant Force	Multi-Linear	Product of Multi-Linear	Resultant Force	Multi-Linear	Product of Multi-Linear
1.91	1.836	1.80375	2.816	2.5	2.72
1.91	1.406	1.5	2.5	2.36	2.43
1.2	1.376	1.33	2.5	3.07	2.9
0.5	1.028	1.021	4.7	2.96	3.27
1.82	1.458	1.52	3	3.125	3.05
1.62	1.488	1.47	2.2	2.42	2.38
0.4	1.058	1.026	0.7	2.6	2.05
2.1	1.806	1.8	3.7	3.07	3.16



Graphs 9, 10, 11 : Variation of cutting forces with special and solid end mill tools from above comparison table

From the above graphs involving variation of forces in case of using special carbide tipped end mill tool and solid carbide k-10 end mill tool, it was found that the cutting forces involved in machining of uni-directional glass polyester composites are less with specially designed carbide tipped tool when compared to solid end mill tool. So there is possibility to obtain reduction of power consumption, tool wear rate and can get good surface finish with specially designed carbide tipped end mill tool.

V. Conclusion

- Factorial Method is convenient to predict the main effects and the interaction effects of different influential combination of end milling process parameters within the range of investigations on cutting forces involved during machining.
- By comparing the cutting forces obtained by use of tools in machining of the GFRP, it was found by application of DOE principles (ANOVA) that the

special carbide tipped tool was found to exert low cutting forces than the regular carbide K-10 end mill tool.

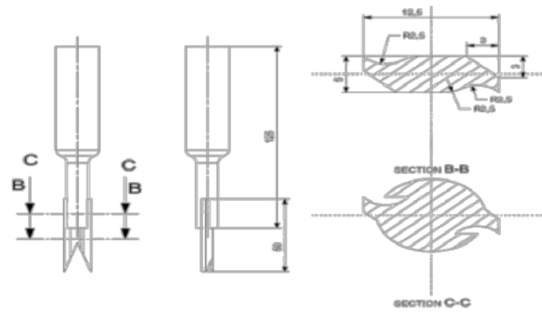
- Hence we can change the nomenclature of special tool, the cutting forces are to be reduced and here proved from correlation of DOE and actual experimental work.
- Factorial Method is easy and accurate method for developing mathematical models for predicting the cutting forces within the working region of the process variables.
- So these kind of specially designed carbide tipped end mill tools are best suitable for machining of GFRP composite laminates in most of industrial applications.

VI. Scope of the Work

In the present investigation it was found that the various process input parameters which effects the cutting forces were studied with their predicted values. In the future work the experiments can be carried out to determining the effect of some other process parameters like spindle diameter, Surface roughness, material removal rate etc., on the machined surfaces in milling operation. Also on further change in nomenclature of special tool the forces can be reduced along with power consumption and tool wear rate, so also tool life increases.

References Références Referencias

1. BHATNAGAR, N.; RAMAKRISHNAN, N.; NAIK, N.K.; KOMANDURAI, R., (1995) *On the machining of fiber Reinforced plastics (FRP) composite laminates, Int J. Machine Tool Manuf.,* v. 35, n. 5, p. 701-716.
2. MONTGOMERY, DC. (1991) *Design and analysis of experiments.* John Wiley and sons, New York.
3. EVESTINE, G. C.; ROGERS. T. G, (1971) *A Theory of machining of fiber reinforced materials, J. Comp. Mater,* n. 5, p 94-105.
4. PALANIKUMAR, K.; KARUNAMOOTHY, L.; KARTHIKEYAN, R. (2006) Assessment of Factors Influencing Surface Roughness on the Machining of Glass Fiber-Reinforced Composites, *J. of Materials and Design,* v. 27, n. 10, p. 862-871.
5. DAVIM, J. P.; MATA, F. (2004) *Influence of cutting parameters on surface roughness using statistical analysis. Indus Lubrication Tribol,* v. 56, n. 5, p. 270-274.
6. R.L. Mason, R.F. Gunst and J.L. ess, *Statistical design and analysis of experiments with applications to engineering and science,* 2003, J. Wiley: New York. p. xix, p. 728.
7. Ramulu, M.; Arola, D.; Colligan, K. (1994) *Preliminary Investigation on the surface Integrity of fiber Reinforced Plastics, Engineering systems.*



Special designed Carbide end mill Tool Details

- Rake Angle : 35 degrees
- Clearance Angle : 8 -10 degrees
- Helix Angle : 30 degrees

End mill tool details

- Rake Angle : 45degrees
- Clearance Angle : 10-12 degrees
- Helix Angle : 35degrees

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Digital Signal Broadcasting of Acoustic Signal Using VHDL

By Anshoo sarswat, Hitendra singh & Rahul Agarwal

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Abstract- Digital signal processing techniques have gained steadily in importance over the past few years in many areas of science and engineering and have transformed the character of instrumentation used in laboratory and plant. This is particularly marked in acoustics, which has both benefited from the developments in signal processing and provided significant stimulus for these developments. As a result acoustical techniques are now used in a very wide range of applications and acoustics is one area in which digital signal processing is exploited to its limits. For example, the development of fast algorithms for computing Fourier transforms and the associated developments in hardware have led to remarkable advances in the use of spectral analysis as a means of investigating the nature and characteristics of acoustic sources. Speech research has benefited considerably in this respect, and, in a rather more technological application, spectral analysis of machinery noise provides information about changes in machine condition which may indicate imminent failure. More recently the observation that human and animal muscles emit low intensity noise suggests that spectral analysis of this noise may yield information about muscle structure and performance.

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DIGITALSIGNALBROADCASTINGOFACOUSTICSIGNALUSINGVHDL

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I. Introduction

a) Signal processing

Signals commonly need to be processed in a variety of ways. For example, the output signal from a transducer may well be contaminated with unwanted electrical "noise". The electrodes attached to a patient's chest when an ECG is taken measure tiny electrical voltage changes due to the activity of the heart and other muscles. The signal is often strongly affected by "mains pickup" due to electrical interference from the mains supply. Processing the signal using a filter circuit can remove or at least reduce the unwanted part of the signal. Increasingly nowadays, the filtering of signals to improve signal quality or to extract important information is done by DSP techniques rather than by analog electronics.DSP and Analog Signal Processing are subfields of Signal Processing.

b) Analog signal processing

Analog signal processing refers to the form of signal processing that is carried out on analog signals and by the use of analog means. The concepts established in analog electronics are used in order to implement the mathematical algorithms that process the analog signals.

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Mathematical values are represented as a continuous physical quantity such as voltage levels, electric current values or electric charge. Small errors or noise that may interfere with such physical quantities can result in corresponding errors in the representation of signals related to these physical quantities.

c) Digital Signal Processing

DSP, or Digital Signal Processing, as the term suggests, is the processing of signals by digital means. A signal in this context can mean a number of different things. Historically the origins of signal processing are in electrical engineering, and a signal here means an electrical signal carried by a wire or telephone line, or perhaps by a radio wave. More generally, however, a signal is a stream of information representing anything from stock prices to data from a remote-sensing satellite. The term "digital" comes from "digit", meaning a number (you count with your fingers - your digits), so "digital" literally means numerical; the French word for digital is numerique. A digital signal consists of a stream of numbers, usually (but not necessarily) in binary form. The processing of a digital signal is done by performing numerical calculations.

Digital signal processing (DSP) is the study of signals in a digital representation and the processing methods of these signals. DSP includes subfields like: audio and speech signal processing , sonar and radar signal processing, sensor array processing, spectral estimation, statistical signal processing, image processing, signal processing for communications, biomedical signal processing, etc.

Since the goal of DSP is usually to measure or filter continuous real-world analog signals, the first step is usually to convert the signal from an analog to a digital form, by using an analog to digital converter. Often, the required output signal is another analog output signal, which requires a digital to analog converter.

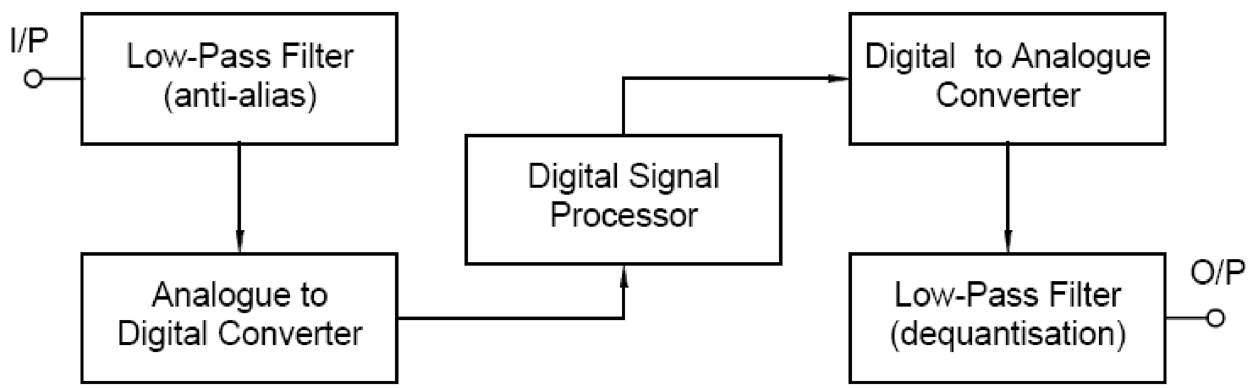
The algorithms required for DSP are sometimes performed using specialized computers, which make use of specialized microprocessors called Digital Signal Processors (also abbreviated DSP). These process signals in realtime and are generally purpose-designed application-specific integrated circuits (ASICs). When flexibility and rapid development are more important than unit costs at high volume, DSP algorithms may also be implemented using field-programmable gate arrays (FPGAs).

d) Analog and digital signals

In many cases, the signal of interest is initially in the form of an analog electrical voltage or current, produced for example by a microphone or some other type of transducer. In some situations, such as the output from the readout system of a CD (compact disc) player, the data is already in digital form. An analog signal must be converted into digital form before DSP techniques can be applied. An analog electrical voltage signal, for example, can be digitised using an electronic circuit called an analog-to-digital converter or ADC. This generates a digital output as a stream of binary numbers whose values represent the electrical voltage input to the device at each sampling instant.

II. Digital Signal Processors (DSPs)

The introduction of the microprocessor in the late 1970's and early 1980's made it possible for DSP techniques to be used in a much wider range of applications. However, general-purpose microprocessors such as the Intel x86 family are not ideally suited to the numerically-intensive requirements of DSP, and during the 1980's the increasing importance of DSP led several major electronics manufacturers (such as Texas Instruments, Analog Devices and Motorola) to develop Digital Signal Processor chips - specialised microprocessors with architectures designed specifically for the types of operations required in digital signal processing. (Note that the acronym DSP can variously mean Digital Signal Processing, the term used for a wide range of techniques for processing signals digitally, or Digital Signal Processor, a specialised type of microprocessor chip). Like a general-purpose microprocessor, a DSP is a programmable device, with its own native instruction code. DSP chips are capable of carrying out millions of floating point operations per second, and like their better-known general-purpose cousins, faster and more powerful versions are continually being introduced. DSPs can also be embedded within complex "system-on-chip" devices, often containing both analog and digital circuitry.



The great advantage of these systems is that their function is easily specified by software. There is an enormous literature on DSP algorithms many of which are of great importance in their own right (e.g. the Fast Fourier Transform). Performance or these systems is usually limited by the performance (i.e. speed, resolution and linearity) of the analogue-to-digital converter.

a) Field-programmable gate array

A field-programmable gate array is a semiconductor device containing programmable logic components called "logic blocks", and programmable interconnects. Logic blocks can be programmed to perform the function of basic logic gates such as AND, and XOR, or more complex combinational functions such as decoders or simple mathematical functions. In most FPGAs, the logic blocks also include memory elements, which may be simple flip-flops or more complete blocks of memories.

A hierarchy of programmable interconnects allows logic blocks to be interconnected as needed by the system designer, somewhat like a one-chip programmable breadboard. Logic blocks and interconnects can be programmed by the customer or designer, after the FPGA is manufactured, to implement any logical function—hence the name "field-programmable".

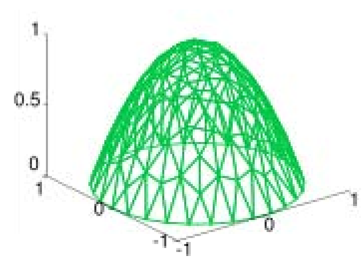
b) Signal sampling

With the increasing use of computers the usage and need of digital signal processing has increased. In order to use an analog signal on a computer it must be digitized with an analog to digital converter (ADC). Sampling is usually carried out in two stages, Discretization and Quantization. In the Discretization stage, the space of signals is partitioned into equivalence classes and Discretization is carried out by replacing the signal with representative signal of the corresponding equivalence class. In the Quantization stage the representative signal values are approximated by values from a finite set.

In order for a sampled analog signal to be exactly reconstructed, the Nyquist-Shannon sampling theorem must be satisfied. This theorem states that the sampling frequency must be greater than twice the bandwidth of the signal. In practice, the sampling frequency is often significantly more than twice the required bandwidth. The most common bandwidth scenarios are: DC - BWx ("baseband"); and Fc +/-BWx, a frequency band centered on a carrier frequency ("direct demodulation").

A digital to analog converter (DAC) is used to convert the digital signal back to analog. The use of a digital computer is a key ingredient into digital control systems

Discretization



A solution to a discretized partial differential equation, obtained with the finite element method.

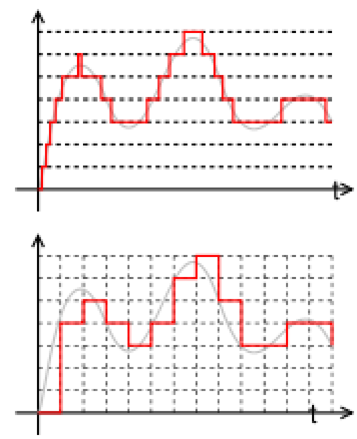
In mathematics, discretization concerns the process of transferring continuous models and equations into discrete counterparts. This process is usually carried out as a first step toward making them suitable for numerical evaluation and implementation on digital computers. In order to be processed on a digital computer another process named quantization is essential.

- Euler discretization
- Zero order hold

Discretization is also related to discrete mathematics, and is an important component of granular computing. In this context, discretization may also refer to modification of variable of category granularity, as when multiple discrete variables are aggregated or multiple discrete categories fused.

c) Quantization

Quantization is the procedure of constraining something to a discrete set of values, such as an integer, rather than a continuous set of values, such as a real number. Quantization in specific domains is discussed in:



Quantized signal

In digital signal processing, quantization is the process of approximating a continuous range of values (or a very large set of possible discrete values) by a relatively-small set of discrete symbols or integer values. More specifically, a signal can be multi-dimensional and quantization need not be applied to all dimensions. Discrete signals (a common mathematical model) need not be quantized, which can be a point of confusion.

A common use of quantization is in the conversion of a discrete signal (a sampledcontinuous signal) into a digital signal by quantizing. Both of these steps (sampling and quantizing) are performed in analog-to-digital converters with the quantization level specified in bits. A specific example would be compact disc (CD) audio which is sampled at 44,100 Hz and quantized with 16 bits (2 bytes) which can be one of 65,536 (i.e. 216) possible values per sample.

III. Dsp Domains

In DSP, engineers usually study digital signals in one of the following domains: time domain (one-dimensional signals), spatial domain (multidimensional signals), frequency domain, autocorrelation domain, and wavelet domains. They choose the domain in which to process a signal by making an informed guess (or by trying different possibilities) as to which domain best represents the essential characteristics of the signal. A sequence of samples from a measuring device produces a time or spatial domain representation, whereas a discrete Fourier transform produces the frequency domain information, that is the frequency spectrum. Autocorrelation is defined as the cross-correlation of the signal with itself over varying intervals of time or space.

a) Time domain

Time domain is a term used to describe the analysis of mathematical functions, or physical signals, with respect to time. In the time domain, the signal or function's value is known for all real numbers, for the case of continuous time, or at various separate instants in the case of discrete time. An oscilloscope is a tool commonly used to visualize real-world signals in the time domain.

b) Frequency domain

Signals are converted from time or space domain to the frequency domain usually through the Fourier transform. The Fourier transform converts the signal information to a magnitude and phase component of each frequency. Often the Fourier transform is converted to the power spectrum, which is the magnitude of each frequency component squared.

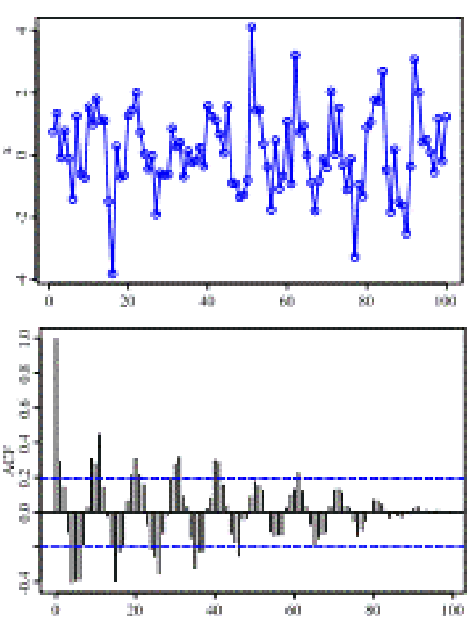
The most common purpose for analysis of signals in the frequency domain is analysis of signal properties. The engineer can study the spectrum to get information of which frequencies are present in the input signal and which are missing.

There are some commonly used frequency domain transformations. For example, the cepstrum converts a signal to the frequency domain through Fourier transform, takes the logarithm, then applies another Fourier transform. This emphasizes the frequency components with smaller magnitude while retaining the order of magnitudes of frequency components.

frequency domain is a term used to describe the analysis of mathematical functions or signals with respect to frequency.

Speaking non-technically, a time domain graph shows how a signal changes over time, whereas a frequency domain graph shows how much of the signal lies within each given frequency band over a range of frequencies. A frequency domain representation can also include information on the phase shift that must be applied to each sinusoid in order to be able to recombine the frequency components to recover the original time signal.

Autocorrelation



A plot showing 100 random numbers with a "hidden" sine function, and an autocorrelation of the series on the bottom.

Autocorrelation is a mathematical tool used frequently in signal processing for analysing functions or series of values, such as time domainsignals. Informally, it is a measure of how well a signal matches a time-shifted version of itself, as a function of the amount of time shift. More precisely, it is the cross-correlation of a signal with itself. Autocorrelation is useful for finding repeating patterns in a signal, such as determining the presence of a periodic signal which has been buried under noise, or identifying the missing fundamental frequency in a signal implied by its harmonic frequencies

IV. Analog Signal Processing vs DSP

There are capabilities which are present in analog signal processing which are absent in digital signal processing, though the latter is often considered to be far more powerful and cheaper. If the original data to be processed is in the analog form, it is expensive and complicated to use devices such as an ADC (analog-to-digital converter) and a DAC (digital-to-analog converter).

These devices are required in order to carry out the conversion of signals from their analog form to the digital form for processing by a digital signal processor (DSP) and back to the analog form for the user to interpret. Instead of deploying such means, it is recommendable to use an analog signal processor. In addition to the added overall complexity of the system, the digital propagation delay that may accompany the processing may reach levels unacceptable for a high-speed system.

Greater levels of efficiency can be achieved by processing analog signals, even if the output data required has to be in digital form. This benefit is manifest in the measurement of alternating current power. In the case of a complex, reactive load, it may become necessary to over-sample the voltage and current signals in order to measure power. An analog multiplier, which is driven by the voltage and current in the load, results in an output that is proportional to the instantaneous power. An integrated and sampled output can be obtained from the output.

a) Applications of analog signal processing

Analog signal processing is used in a number of engineering applications. Analog signal processors are used when the signal manipulation has to be carried out in a simple manner, unlike other complicated methods. Analog multipliers and dividers provide easy gain control and are useful in applications like continuous power measurement. They are used in ratiometric functions and have a considerably high accuracy rate of the order of 1%.

b) Applications of DSP

DSP technology is nowadays commonplace in such devices as mobile phones, multimedia computers, video recorders, CD players, hard disc drive controllers and modems, and will soon replace analog circuitry in TV sets and telephones. An important application of DSP is in signal compression and decompression. Signal compression is used in digital cellular phones to allow a greater number of calls to be handled simultaneously within each local "cell". DSP signal compression technology allows people not only to talk to one another but also to see one another on their computer screens, using small video cameras mounted on the computer monitors, with only a conventional telephone line linking them together. In audio CD systems, DSP technology is used to perform complex error detection and correction on the raw data as it is read from the CD.

Although some of the mathematical theory underlying DSP techniques, such as Fourier and Hilbert Transforms, digital filter design and signal compression, can be fairly complex, the numerical operations required actually to implement these techniques are very simple, consisting mainly of operations that could be done on a cheap four-function calculator. The architecture of a DSP chip is designed to carry out such operations incredibly fast, processing hundreds of millions of samples every second, to provide real-time performance: that is, the ability to process a signal "live" as it is sampled and then output the processed signal, for example to a loudspeaker or video display. All of the practical examples of DSP applications mentioned earlier, such as hard disc drives and mobile phones, demand real-time operation.

The major electronics manufacturers have invested heavily in DSP technology. Because they now find application in mass-market products, DSP chips account for a substantial proportion of the world market for electronic devices. Sales amount to billions of dollars annually, and seem likely to continue to increase rapidly.

V. Applications

The main applications of DSP are audio signal processing, audio compression, digital image processing, video compression, speech processing,speech recognistion digital communication, RADAR, SONAR, seismology, and biomedicine. Specific examples are speech compression and transmission in digital mobile phones, room matching equalisation of sound in Hifi and sound reinforcement applications, weather forcasting, economic forcasting,seisemic data processing, analysis and control of industrial processes, computer-generated animations in movies ,medical imaging such as CAT scans and MRI, image manupulation, high fidelity loudspeaker crossovers and equalization, and audio effect for use with electric guitar amplifiers

a) Speech processing

Speech processing is the study of speech signals and the processing methods of these signals.

The signals are usually processed in a digital representation whereby speech processing can be seen as the intersection of digital signal processing and natural language processing.

Speech processing can be divided in the following categories:

- Speech recognition, which deals with analysis of the linguistic content of a speech signal.
- Speaker recognition, where the aim is to recognize the identity of the speaker.
- Enhancement of speech signals, e.g. noise reduction,
- Speech coding, a specialized form of data compression, is important in the telecommunication area.
- Voice analysis for medical purposes, such as analysis of vocal loading and dysfunction of the vocal cords.
- Speech synthesis: the artificial synthesis of speech, which usually means computer generated speech

b) Video compression

Video compression refers to reducing the quantity of data used to represent video images, and this is almost always coupled with the goal of retaining as much of the original's quality as possible. Compressed video can effectively reduce the bandwidth required to transmit digital video via terrestrial broadcast, via cable, or via satellite services.

Most video compression is lossy, i.e. it operates on the premise that much of the data present before compression is not necessary for achieving good perceptual quality. For example, DVDs use a video coding standard called MPEG-2 that can compress ~2 hours of video data by 15 to 30 times while still producing a picture quality that is generally considered high quality for standard-definition video. Video compression, like data compression, is a tradeoff between disk space, video quality and the cost of hardware required to decompress the video in a reasonable time. However, if the video is overcompressed in a lossy manner, visible (and sometimes distracting) artifacts can appear.

c) Audio compression

It has been suggested that this article or section be merged with voice compression. (Discuss)

Audio compression can mean two things:

- Audio data compression - in which the amount of data in a recorded waveform is reduced for transmission. This is used in CD and MP3 encoding, internet radio, and the like.
- Audio level compression - in which the dynamic range (difference between loud and quiet) of an

audio waveform is reduced. This is used in guitar effects racks, recording studios, etc.

d) Audio signal processing

Audio signal processing, sometimes referred to as audio processing, is the processing of a representation of auditory signals, or sound. The representation can be digital or analog.

The focus in audio signal processing is most typically a mathematical analysis of which parts of the signal are audible. For example, a signal can be modified for different purposes such that the modification is controlled in the auditory domain.

The parts of the signal are heard and which are not, is not decided merely by physiology of the human hearing system, but very much by psychological properties. These properties are analysed within the field of psychoacoustics.

e) Application areas

Processing methods and application areas include storage, level compression, data compression, transmission, enhancement (e.g., equalization, filtering, noise cancellation, echo or reverb removal or addition, etc.)

f) Audio Broadcasting

Audio broadcasting (be it for television or audio broadcasting) is perhaps the biggest market segment (and user area) for audio processing products -- globally.

Traditionally the most important audio processing (in audio broadcasting) takes place just before the transmitter. Studio audio processing is limited in the modern era due to digital audio systems (mixers, routers) being pervasive in the studio.

In audio broadcasting, the audio processor must

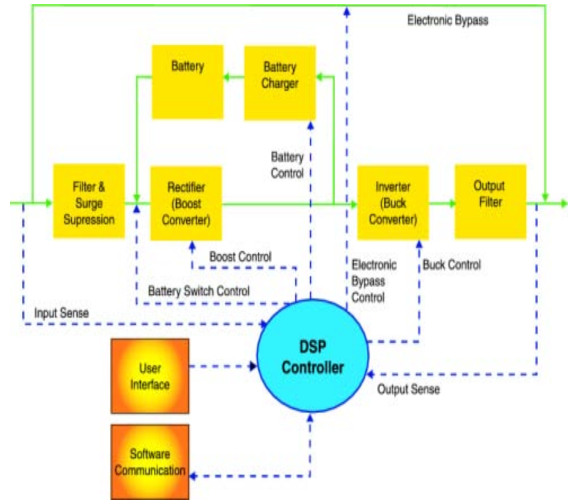
- prevent overmodulation, and minimize it when it occurs
- maximize overall loudness
- compensate for non-linear transmitters, more common with medium wave and shortwave broadcasting

VI. Development of DSP

The development of digital signal processing dates from the 1960's with the use of mainframe digital computers for number-crunching applications such as the Fast Fourier Transform (FFT), which allows the frequency spectrum of a signal to be computed rapidly. These techniques were not widely used at that time, because suitable computing equipment was generally available only in universities and other scientific research institutions.

a) The DSP Advances UPS Design

When electrical utility power fails or drops to an unacceptable level, uninterruptible power systems (UPS) are key in saving and protecting valuable computer data. Uninterruptible power systems equipment provides power conditioning, power regulation, and - in case of a power outage - provides the crucial backup power needed for an orderly shutdown of computer processes and files.



Originally designed for mathematically and computationally intensive motor drive control processes, DSPs now have expanded capabilities such as faster machine-cycle speeds and enhanced programming instruction sets.

Digital signal processors now also offer peripheral functionality such as onboard counters and timers, analog-to Crowded data centers and racks filled from top to bottom with storage devices, monitors, servers, communications devices and other equipment are driving the need for UPS technology with increased power efficiency, within a compact and sleek form factor. For end users and facilities managers, "thin is in", and so UPS designers continually strive for smaller products, fewer parts, lower cost and less weight. Digital signal processor (DSP) controllers are an enabling technology for meeting the challenge of such design requirements. Digital signal processors are now propelling many of the advances in UPS design.

As illustrated in the block diagram, the DSP controller manages many UPS functions, including:

- sensing and controlling input and output voltage and current levels,
- setting and controlling the rectifier (a boost converter) for input power-factor correction and for regulating the dc voltage into the inverter,
- setting and controlling the inverter (a buck converter) for output voltage and frequency regulation,
- controlling the battery charger,
- interfacing with power management software through communication port cards, and \
- switching to electronic bypass

digital converters, pulse-width-modulation outputs, flash memory, and controller-area network communications. The similarities between motor drive controls and UPS controls, combined with the enhanced functionality of DSPs, contribute to making the UPS a "natural" application for DSPs.

Lower-cost, high-performance DSP controllers provide an improved and cost-effective solution for UPS design. Digital signal processors allow UPS designers to replace bulky transformers, relays and mechanical bypass switches with smaller, more intelligent functional equivalents. Digital signal processor implementations also facilitate other design benefits, including increased power efficiency and increased power density - smaller product footprint with less weight - a necessity in space-constrained data centers.

In UPS applications, the DSP has integrated functions selected for sophisticated embedded controls. These functions, previously available only through more expensive microcontrollers and off-board peripheral circuitry, include protection circuitry, clocks and serial communications, in addition to the peripheral DSP functionality previously mentioned. Except for signal conditioning and actuators that provide the interface between the DSP and the power circuitry, all the control implementations become digital. Multiple control algorithms can execute almost simultaneously and at high machine-cycle speeds for unprecedented dynamic performance. The DSP implementation also has fewer parts, increased reliability and greater immunity to noise than predecessor microcontroller implementations. Since the DSP feedback and control loops are implemented digitally, compensation for component tolerances and temperature variations of feedback elements is no longer necessary. Digital signal processor technology provides a cost-effective alternative for controlling multiple power converters, either individually or in combination, to meet the demands of advanced power topologies.

b) Advances in Hearing aid Technology

i. *How do hearing aids work?*

Hearing aids use electronic circuits to help compensate for your hearing loss. They selectively make sounds louder to improve your ability to hear and understand speech. They work by increasing the pitch range of sounds. Pitch is the quality of the sound that enables you to classify it as high or low.

ii. *What is digital signal processing?*

Most hearing aids dispensed at Cleveland Clinic are digital hearing aids. Simply put, a digital hearing aid converts the sound coming into the microphone into a signal that can be processed or changed by a digital computer chip. The signal is then converted back intosound and is delivered to the ear. Like a CD player, digital hearing aids deliver a crisp, clean sound. These hearing aids automatically adjust the amount of gain given to a sound based on how loud it is. In addition to being a crisp, clean sound, this can also make the digital hearing aid more comfortable to listen to.

The main advantage of digital hearing aids is that they allow for flexibility in processing sound that is not possible with analogue technology. Some of these advantages are described below:

- Adaptive directional microphones: Directional microphones have been available in hearing aids, however only digital aids hearing allow for adaptive directional microphone capabilities. Directional microphones can help to reduce the sounds coming from behind a person by turning on a second microphone in the hearing aid. Adaptive directional microphones do the same things, but can move around to find the loudest noise source or in some cases reduce multiple noise sources at the same time.
- Digital feedback suppression (DFS): Feedback, or whistling, is monitored by this DFS system while you wear your hearing aid and is selectively reduced or eliminated without reducing the gain in the hearing aid. This system is especially helpful for hearing aid users who experience feedback while chewing or talking.
- Digital noise reduction: Digital signal processing allows the hearing aids to monitor the environment for steady noise sources and reduce the level of these noises. This system can help to reduce the annoyance caused by noise sources and possibly improve speech understanding.

iii. *What can I expect from my hearing aids?*

Unlike eyeglasses, hearing aids cannot provide complete correction for the impairment. No hearing aid will restore your hearing to normal or provide a perfect substitute for normal hearing. The benefits derived from wearing hearings aids, even the most technologically advanced, will vary from person to person. Digital signal processing makes the most of your hearing capacity, improves sound quality, and can be "fine-tuned" to help meet your individual listening needs.

DSPs in 2007

Today's signal processors yield much greater performance. This is due in part to both technological and architectural advancements like lower design rules, fast-access two-level cache, (E)DMA circuit and a wider bus system. Of course, not all DSPs provide the same speed and many kinds of signal processors exist, each one of them being better suited for a specific task, ranging in price from about US$1.50 to US$300. A Texas Instruments C6000 series DSP clocks at 1 GHz and implements separate instruction and data caches as well as a 8 MiB 2nd level cache, and its I/O speed is rapid thanks to its 64 EDMA channels. The top models

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are capable of even 8000 MIPS (million instructions per second), use VLIW encoding, perform eight operations per clock-cycle and are compatible with a broad range of external peripherals and various buses (PCI/serial/etc).

Another big signal processor manufacturer today is Analog Devices. The company provides a broad range of DSPs, but its main portfolio is multimedia processors, such as codecs, filters and digital-analog converters. Its SHARC-based processors range in performance from 66 MHz/198 MFLOPS (million floating-point operations per second) to 400 MHz/2400MFLOPS. Some models even support multiple multipliers and ALUs, SIMD instructions and audio processing-specific components and peripherals. Another product of the company is the Blackfin family of embedded digital signal processors, with models like the ADSP-BF531 to ADSP-BF536. These processors combine the features of a DSP with those of a general use processor. As a result, these processors can run simple operating systems like μCLinux, velOSity and Nucleus RTOS while operating relatively efficiently on real-time data.

Most DSPs use fixed-point arithmetic, because in real world signal processing, the additional range provided by floating point is not needed, and there is a large speed benefit and cost benefit due to reduced hardware complexity. Floating point DSPs may be invaluable in applications where a wide dynamic range is required. Product developers might also use floating point DSPs to reduce the cost and complexity of software development in exchange for more expensive hardware, since it is generally easier to implement algorithms in floating point.

General purpose CPUs have borrowed concepts from digital signal processors, exemplified by many new instructions present in the MMX and SSE extensions to the IntelIA-32 architecture instruction set (ISA).

Generally, DSPs are dedicated integrated circuits, however DSP functionality can also be realized using Field Programmable Gate Array chips.

Embedded general-purpose RISC processors are becoming increasingly DSP in functionality. For example, ARM Cortex-A8 has a 128-bit wide SIMD unit that can have impressive 16- and 8-bit performance for industry standard benchmarks.

VII. Conclusion

Realtime signal processing is taking the digital revolution to the next step, making equipment that is more personal, more powerful, and more interconnected than most people ever imagined possible. Over the years, different technologies have powered the most innovative creations from the mainframe and minicomputer eras to the PC and today's Internet era. Consumers are driving realtime functionality, demanding equipment that is extremely fast, portable, and flexible. To meet those needs, designers are facing more pressures than ever, but they also have more options than ever to address them.

Careful evaluation of each option clearly shows several viable alternatives for embedded applications. For implementing today's realtime signal processing applications, however, DSP is very often the best choice. No digital technology has more strengths than DSP nor better meets the stringent criteria of today's developer. Certainly, other digital options can address any one of these relevant problems well, but only with clear trade-offs.

DSP gives designers the best combination of power, performance, price, and flexibility and allows them to deliver their realtime applications quickly to the market.

References Références Referencias

1. Discrete-Time Signal Processing (2nd Edition) (Prentice-Hall Signal Processing Series) by Ronald W. Schafer.
2. Understanding Digital Signal Processing by Richard G. Lyons.
3. Modern Spectral Estimation: Theory and Application/Book and Disk (Prentice-Hall signal processing series) by Steven M. Kay.

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Multi-Body Dynamic Modeling and Simulation of Crawler-Formation Interactions in Surface Mining Operations – Crawler Kinematics

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Abstract- Surface mining operations use large tracked shovels to achieve economic bulk production capacities. Shovel reliability, maintainability, availability and efficiency depend on the service life of the crawlers. In rugged and challenging terrains, the extent of crawler wear, tear, cracks and fatigue failure can be extensive resulting in prolonged downtimes with severe economic implications. In particular, crawler shoe wear, tear, cracks and fatigue failures can be expensive in terms of maintenance costs and production losses. This research study is a pioneering effort for understanding and providing long-term solutions to crawler-formation problems in surface mining applications. The external forces acting on the crawler shoes and oil sand are formulated to determine system kinematics. The dynamic model focuses on the external force from machine weight, the crawler contact forces, the contact friction forces and the inertia and gravity forces using multi-body dynamics theory. A virtual prototype simulator of the crawler dynamics is simulated within the MSC ADAMS environment.

Keywords: *surface mining, crawler-terrain interactions, multi-body dynamic theory, crawler dynamic modeling, virtual prototype simulation.*

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MULTI-BODYDYNAMICMODELINGANDSIMULATIONOFCRAWLER-FORMATIONINTERACTIONSINSURFACEMININGOPERATIONSCRAWLERKINEMATICS

Strictly as per the compliance and regulations of :

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Samuel Frimpong [α] & Magesh Thiruvengadam [σ]

Abstract- Surface mining operations use large tracked shovels to achieve economic bulk production capacities. Shovel reliability, maintainability, availability and efficiency depend on the service life of the crawlers. In rugged and challenging terrains, the extent of crawler wear, tear, cracks and fatigue failure can be extensive resulting in prolonged downtimes with severe economic implications. In particular, crawler shoe wear, tear, cracks and fatigue failures can be expensive in terms of maintenance costs and production losses. This research study is a pioneering effort for understanding and providing long-term solutions to crawler-formation problems in surface mining applications. The external forces acting on the crawler shoes and oil sand are formulated to determine system kinematics. The dynamic model focuses on the external force from machine weight, the crawler contact forces, the contact friction forces and the inertia and gravity forces using multi-body dynamics theory. A virtual prototype simulator of the crawler dynamics is simulated within the MSC ADAMS environment. The simulation results for kinematics (displacement, velocities and accelerations) of selected crawler track shoes are presented. The results show that during translation motion, the track's maximum lateral slide and vertical bounce from the equilibrium position are 1 cm and 3.5 cm respectively. The corresponding magnitudes of maximum lateral and bouncing velocities and accelerations are about 0.06 m/s and 0.45 m/s and 1.8 m/s2 and 27.0 m/s2 respectively. The crawler track also rotates while translating with angular velocities about x, y and z axes reaching maximum magnitudes of 12.5 deg/s, 73.0 deg/s and 1.6 deg/s. During the turning motion, the crawler track experiences varying bouncing and rolling motions causing its maximum lateral velocity to increase 5 times and vertical bouncing velocities to increase 9 times the maximum values encountered during translation. This study provides guidelines to simulate flexible crawler track-bench interactions in oil-sand mine for predicting and improving fatigue life during dynamic loading of the crawler shoes.

Keywords: surface mining, crawler-terrain interactions, multi-body dynamic theory, crawler dynamic modeling, virtual prototype simulation.

I. Introduction

Cable shovels are widely used in surface mining operations. The lower works of this shovel comprise propel and crawler systems, which

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The crawler tracks are made up of shoes that are connected together by link pins to form a continuous chain [2]. Multi-body dynamics study on crawler-terrain interactions is non- existent for large shovels in surface mining operations but it is required to provide knowledge of crawler performance and fatigue life. Fatigue life modeling and analysis are also required to develop preventive maintenance plans, component replacements and rebuilds to extend the life of the crawlers and reduce their maintenance costs. Nakanishi and Shabana (1994) used a 2-D hydraulic excavator model to study the multi-body dynamics of a tracked vehicle. The track interaction with sprockets, rollers and ground were modeled using the spring-damper force to calculate the track-terrain normal contact forces. The tangential force was modeled using a simple Coulomb friction model. Choi et al. (1998) and Lee et al. (1998) extended the 2-D study of Nakanishi and Shabana (1994) to a 3-D contact force models of a hydraulic excavator.

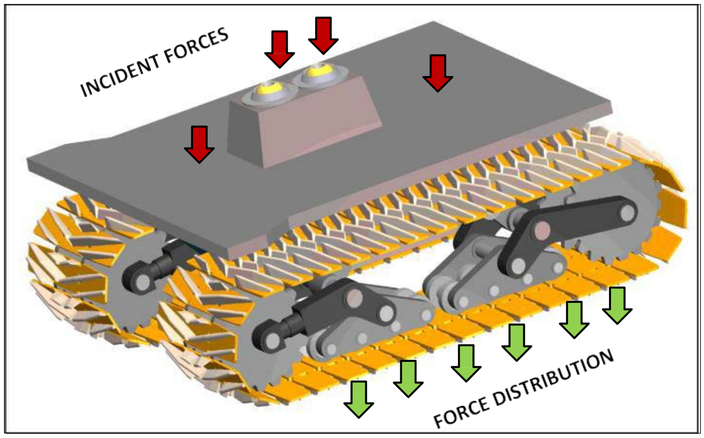

Figure 1: 4100C BOSS Electric Mining Shovel [1]

Rubinstein and Hitron (2004) used an LMS-DADS simulation to develop a multi-body dynamic M113 armored carrier tracked vehicle simulator. Hertz theory was used to model the track- terrain contact force, and user-defined force elements to calculate normal and tangential forces between the track and the terrain. Rubinstein and Coppock (2007) extended this model by including grousers in the track-terrain model. Ferretti and Girelli (1999) developed a 3-D dynamic model of an agricultural tracked vehicle using Newton-Euler rigid-body theory. They introduced a track-terrain model using soil mechanics theory to generate the dynamics of the system. They used these parameters as input in the dynamic model to calculate sinkage and shear displacement of the track.

Ryu et al. (2000) developed a computational method for a non-linear dynamic model of military tracked vehicle. They used compliant force elements between the pins and track links to increase the degrees of freedom (DOF) based on the track-terrain contact force model by Choi et al. (1998). Madsen (2007) used MSC ADAMS to simulate a complex tracked hydraulic excavator. The model used the contact force model in ADAMS to define the crawler-terrain interactions. Ma and Perkins (1999) developed a hybrid track model for a large mining shovel crawler using continuous and multi-body track model. A commercial multi-body dynamics code, DADS, was used to assemble the continuous and multi-body track vehicle model. Their study was limited to studying a 2-D dynamic contact between track and sprocket during the propel motion.

Previous research on multi-body dynamic models has also focused on shovel dipper-bank interactions. Frimpong et al. (2005) used an iterative Newton-Euler method to develop a dynamic model of boom, dipper handle and dipper assembly. Their dynamic model identified the important factors that determine the performance of the shovel during its digging phase. Frimpong and Li (2007) also modeled the interaction between the dipper of a cable shovel and oil sands formation using multi-body dynamics theory. In addition, the shovel boom was made flexible to determine its deformation and stress distribution during shovel operations.

Frimpong and Thiruvengadam (2015) have formulated the kinematics of the crawler-flexible terrain interactions of a large mining shovel in surface mining operations (P&H 4100C BOSS Electric Shovel in Figure 1). They showed that 132 DOFs in the crawler-terrain system are driven by external forces and dynamic analysis is required to generate the remaining DOFs. This paper advances the kinematic models to formulate the dynamic models for the crawler-terrain interactions based on the rigid multi-body dynamics theory [14, 15, 16 and 17].

II. Rigid Multi-body Dynamics of Crawler-Terrain Interactions

Figure 2 illustrates the geometry of the crawler track assemblies for the P&H 4100C Boss shovel. The track is modeled using the crawler track dimensions given in Table 1. Only the open track chain of the crawler assembly, in contact with the ground (Figure 1), is used for this study. Since the crawler track is made up of crawler shoes, a simplified crawler shoe model is developed first and then connected together to form the multi-body model of track assembly. This simplified model is generated in Solidworks based on the actual crawler shoe model for P&H 4100C Boss shovel [18].

Table 1: Mass properties of system [13, 18]

Body	Density (kg/m^3)	Volume (m^3)	Mass (kg)
Crawler Shoe	7847.25	0.5966	4681.67
Oil-sand unit	1600.0	98.0	1.568 x 105

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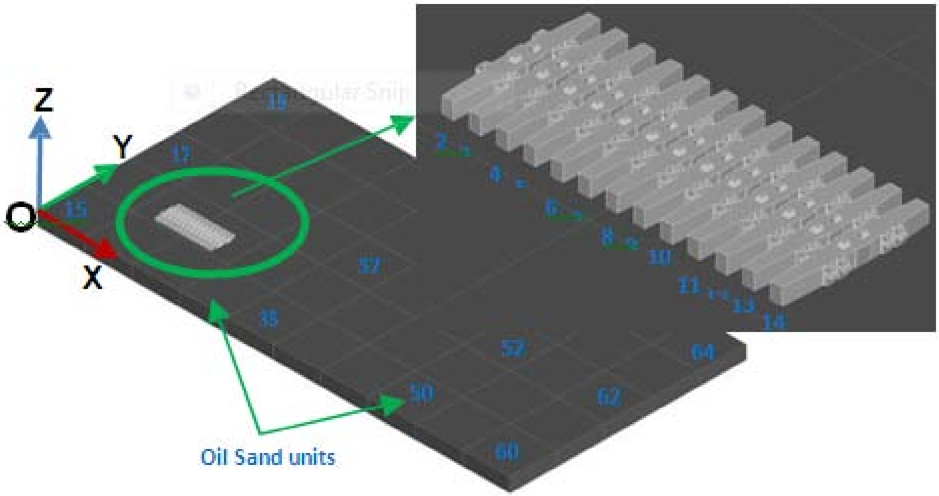

Figure 2 : Crawler track assembly interacting with the ground

The mass moment of inertia of each body in the system used for the dynamic analysis [19, 20 and 21] is obtained directly from MSC ADAMS. The crawler shoes 2-14 are identical and all of them have the same mass moment of inertia about their centers of mass.

III. Dynamic Equations of Motion

The shovel weight (W), supported by two crawlers, is uniformly distributed on the crawler shoes that are in contact with the ground [2]. This study focuses only on the crawler shoes in contact with the ground for one crawler track. This crawler track segment along with one half of the vehicle load (W/2) acting on it is shown in Figure 3. From Wong (2001), when the vehicle sinks vertically to the ground the ground exerts normal force (FN), and tangential force (FT) (longitudinal and lateral) on the crawler track segment as shown in Figure 3. These normal and tangential forces are modeled using inbuilt contact force mechanism in MSC ADAMS.

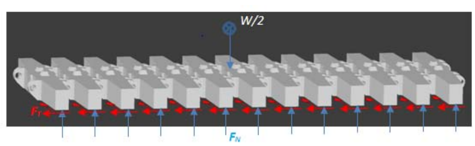

Figure 3 : Ground Forces acting on the shovel crawler track

Crawler shoes dynamic equilibrium for link i: In the multi-body model shown in Figure 2, the weight (W/2) is assumed to be equally shared by thirteen crawler shoes. The uniformly distributed load (w^i) applied on each shoe is in addition to its self-weight. The mass of the crawler shoe is assumed as *mi*. The free body diagram of a crawler shoe *i* with inertia forces in dynamic equilibrium with external and joint constraint forces is shown in Figure 4 [14, 22 and 23]. The external forces acting on the crawler shoe # *i* are the gravity force (*mig*) due to selfweight of the shoe, uniformly distributed load (*wi*) due to machine weight and contact forces (F_C^i, M_C^i) due to the interaction between crawler shoe and ground as shown in Figure 3. The joint forces are due to reactive fo rces at the spherical joints $(F_S^{i-1,i}, M_S^{i-1,}$ and $F_S^{i,i+1}, M_S^{i,i+1})$ and parallel primitive joints $(F_P^{i-1,i}$, $M_P^{i-1,i}$ and $F_P^{i,i+1}, M_P^{i,i+1})$ as shown in Figure 4.

The following dynamic equation of motion uses the notations and formulation described in Shabana [14, 15]. The dynamic equations of motion for the constrained rigid body *i* using centroidal body coordinate system from Shabana [14, 15] is given by equation (1).

$$\mathbf{M}^i\ddot{\mathbf{q}}^i - \mathbf{Q}_v^i = \mathbf{Q}_e^i + \mathbf{Q}_c^i \tag{1}$$

i = 2, 3,…,14 for crawler shoes and *i* = 15, 16,…,64 for oil sand units.

Generalized Inertia Forces of Crawler shoe i = 2, 3,…,14: The generalized inertia force is given by the left hand side of the equation 1. From Shabana [14, 15]

$$\mathbf{M}^i = \begin{bmatrix} \mathbf{m}_{RR}^i & \mathbf{0} \\ \mathbf{0} & \mathbf{m}_{\theta\theta}^i \end{bmatrix} = \text{Mass matrix of the crawler shoe } i \tag{2}$$

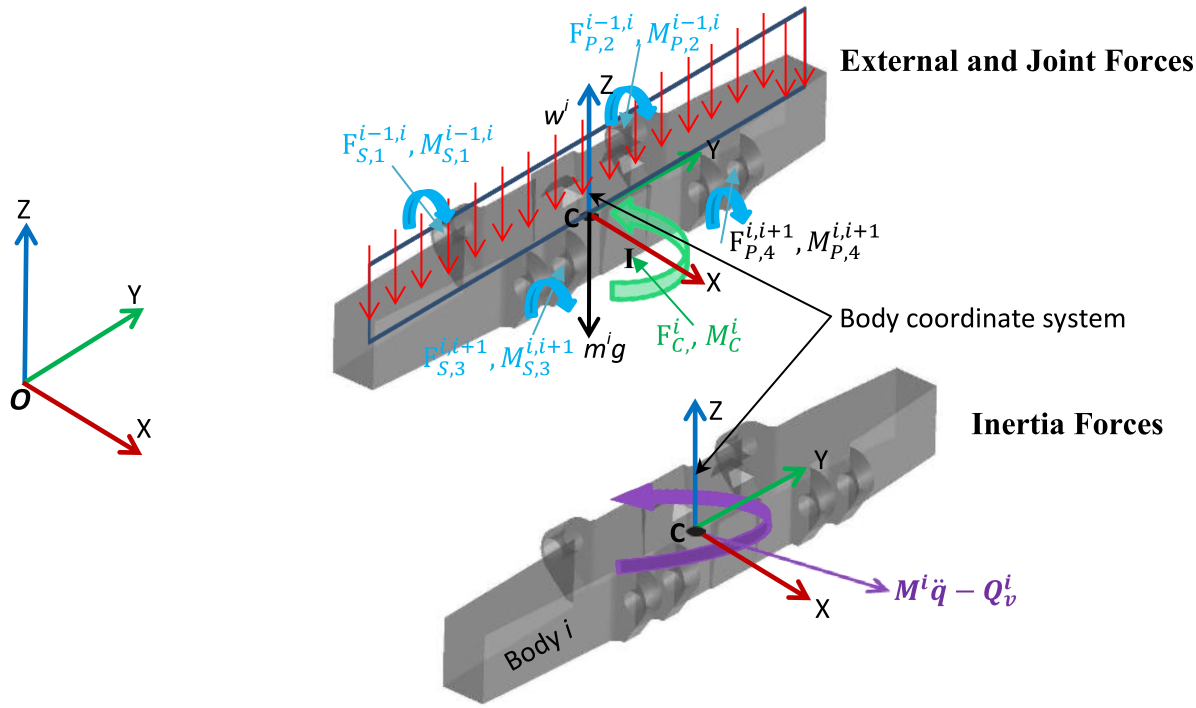

Figure 4 : Dynamic equilibrium of the rigid crawler shoe

$$\mathbf{Q}_v^i = \begin{bmatrix} 0 \\ (\mathbf{Q}_v^i)_\theta \end{bmatrix} = \text{Vector of generalized quadratic velocity vector} \tag{3}$$

$$\ddot{\mathbf{q}}^i = [\ddot{\mathrm{R}}_x^i \quad \ddot{\mathrm{R}}_y^i \quad \ddot{\mathrm{R}}_z^i \quad \ddot{\phi}^i \quad \ddot{\theta}^i \quad \ddot{\psi}^i]^T = \text{ of generalized acceleration of body} \tag{4}$$

$$\mathbf{m}_{\mathbf{RR}}^i = \begin{bmatrix} m^i & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & m^i & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & m^i \end{bmatrix} \tag{5}$$

$$\mathbf{m}_{\theta\theta}^i = \overline{\mathbf{G}}^{i\mathbf{T}} \overline{\mathbf{I}}_{\theta\theta}^i \overline{\mathbf{G}}^i \tag{6}$$

$$(\mathbf{Q}_v^i)_\theta = -\overline{\mathbf{G}}^{i\mathrm{T}}[\overline{\boldsymbol{\omega}}^i \times (\overline{\mathbf{I}}_{\theta\theta}^i \overline{\boldsymbol{\omega}}^i) + \overline{\mathbf{I}}_{\theta\theta}^i \dot{\overline{\mathbf{G}}}^i \dot{\boldsymbol{\theta}}] \tag{7}$$

Equation (7) is the generalized quadratic velocity vector associated with the orientation coordinates ($\boldsymbol{\theta}$). In equation (7),

$$\overline{\mathbf{G}}^i = \begin{bmatrix} \sin\theta^i \sin\psi^i & \cos\psi^i & 0 \\ \sin\theta^i \sin\psi^i & -\sin\psi^i & 0 \\ \cos\theta^i & 0 & 1 \end{bmatrix} \tag{8}$$

$$\overline{\boldsymbol{\omega}}^i = \overline{\mathbf{G}}^i \dot{\boldsymbol{\theta}}^i \tag{9}$$

$$\overline{\mathbf{I}}_{\theta\theta}^i = \begin{bmatrix} \mathrm{I}_{XX} & \mathrm{I}_{XY} & \mathrm{I}_{XZ} \\ \mathrm{I}_{YX} & \mathrm{I}_{YY} & \mathrm{I}_{YX} \\ \mathrm{I}_{ZX} & \mathrm{I}_{ZY} & \mathrm{I}_{ZZ} \end{bmatrix} \tag{10}$$

Equation (8) is the unit vectors along the x, y, z axis of the centroidal coordinate system of body i; and $\overline{\mathbf{I}}_{\theta\theta}^i$ = inertia tensor [14, 22 and 23] of shoe i in its centroidal coordinate system aligned with global coordinate system shown in Figure 2. Equation (9) is the angular velocity vector in the body coordinate system.

Generalized External Forces acting on crawler shoe i = 2, 3,…, 14: The first term on the RHS of equation (1) gives the generalized external forces in the crawler track multi-body system [14].

$$\mathbf{Q}_{\mathbf{e}}^{i}=\begin{bmatrix}\left(\mathbf{Q}_{\mathbf{e}}^{i}\right)_{\mathbf{R}}\\ \left(\mathbf{Q}_{\mathbf{e}}^{i}\right)_{\boldsymbol{\theta}}\end{bmatrix} \tag{11}$$

$\left(\mathbf{Q}_{\mathbf{e}}^{i}\right)_{R}$ is the vector of generalized applied forces associated with the translation coordinates $\mathbf{R}$);

$\left(\mathbf{Q}_{\mathbf{e}}^{i}\right)_{\theta}$ is the vector of generalized applied forces associated with the orientation coordinates ($\boldsymbol{\theta}$).

The gravity force, distributed machine load, and contact forces are the external forces acting on the crawler system. The generalized external forces are obtained from Shabana [14, 15].

The self-weight of the crawler shoe due to its mass (m^i)acting at its centroid C is shown in Figure 4. The mass of the crawler shoe from Table 1 = m^i = 4681.67 kg and the gravity force acting at the center of mass of each crawler shoe = $m^i g$ = 432.3 KN. The gravity force vector ($\mathbf{F}_g^i$) acting on each crawler shoe i in the global coordinate system = $\begin{bmatrix}0 & 0 & -m^i g\end{bmatrix}^T$ The generalized forces, associated with the gravity force, are given as equations (12) and (13).

$$\mathbf{Q}_{\mathbf{R}}^{i}=\begin{bmatrix}\mathrm{Q}_{x}^{i}\\ \mathrm{Q}_{y}^{i}\\ \mathrm{Q}_{z}^{i}\end{bmatrix}=\mathbf{F}_{g}^{i}=\begin{bmatrix}0\\ 0\\ -m^{i}g\end{bmatrix} \tag{12}$$

$$\mathbf{Q}_{\boldsymbol{\theta}}^{i}=-\left(\mathbf{A}^{i}\tilde{\bar{\mathbf{u}}}_{\mathbf{C}}^{i}\bar{\mathbf{G}}^{i}\right)^{T}\mathbf{F}_{g}^{i} \tag{13}$$

$$\tilde{\bar{\mathbf{u}}}_{C}^{i}=\begin{bmatrix}0 & -\bar{z}_{c}^{i} & \bar{y}_{c}^{i}\\ \bar{z}_{c}^{i} & 0 & -\bar{x}_{c}^{i}\\ -\bar{y}_{c}^{i} & \bar{x}_{c}^{i} & 0\end{bmatrix} \tag{14}$$

$\mathbf{A}^i$ is a transformation matrix given in Frimpong and Thiruvengadam (2015); equation (14) is a skew symmetric matrix associated with the vector $\bar{\mathbf{u}}_C^i$; and $\bar{\mathbf{u}}_C^i=\begin{bmatrix}\bar{x}_c^i & \bar{y}_c^i & \bar{z}_c^i\end{bmatrix}^T$ is the position vectorof center of mass of body i with respect to the origin of the body coordinate system. Since the origin of the reference point of body i coincide with the center of the mass of body i, the vector $\bar{\mathbf{u}}_C^i$ =0.Therefore, $\mathbf{Q}_{\boldsymbol{\theta}}^i=\mathbf{0}$. These generalized forces are added to the generalized external force vector $\mathbf{Q}_e^i$ in equation (1).

The distributed load on each crawler shoe is due to the weight of the machine. The total machine load, excluding the weight of the crawler shoes in contact with the ground, is assumed to be distributed uniformly on each crawler shoe as shown in Figure 4. For example, the total machine weight [1] is 1,410,184 kg. Half of this weight is 705,092 kg. The total number of crawler shoes in contact with the ground (for the P&H 4100C BOSS) is 16, and thus, the total weight of 16 crawler shoe is 74,907 kg. Therefore the distributed weight (w^i) on each crawler shoe in contact with the ground is equal to 39,387 kg. This research focuses on the total force and moment exerted by the distributed load.

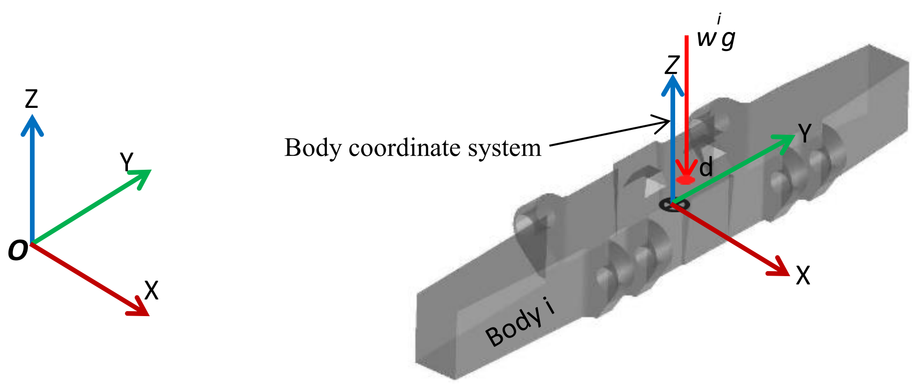

Figure 5: *Equivalent distributed load on the crawler shoe*

This distributed load can be represented by a single equivalent force ($w^i g$= 386.4 kN) and is assumed to pass through the centroid (d) of the top surface of each crawler shoe i as shown in Figure 5. The distributed force vector ($\mathbf{F}_d^i$) acting on each crawler shoe i in the global coordinate system =$\begin{bmatrix}0 & 0 & -w^i g\end{bmatrix}^T$. The generalized forces associated with the distributed force from Shabana (2010) are given by equations (15) and (16).

$$\mathbf{Q}_{\mathbf{R}}^{i}=\begin{bmatrix}Q_{x}^{i}\\ Q_{y}^{i}\\ Q_{z}^{i}\end{bmatrix}=\mathbf{F}_{\mathbf{d}}^{i}=\begin{bmatrix}0\\ 0\\ -w^{i}g\end{bmatrix} \tag{15}$$

$$\mathbf{Q}_{\theta}^{i} = -\left(\mathbf{A}^{i}\tilde{\bar{\mathbf{u}}}_{d}^{i}\bar{\mathbf{G}}^{i}\right)^{T}\mathbf{F}_{d}^{i} \tag{16}$$

$\bar{\mathbf{u}}_{d}^{i} = \left[\bar{x}_{d}^{i}\ \ \bar{y}_{d}^{i}\ \ \bar{z}_{d}^{i}\right]^{T}$ is the position vector of point of application of equivalent force $\mathbf{F}_{d}^{i}$ with respect to the origin of the body coordinate system. These generalized forces are added to the generalized external force vector $\mathbf{Q}_{e}^{i}$ in equation (1).

Contact force between crawler shoe and ground: Figure 4 also shows the 3-D contact forces (normal and tangential) and the torque between track shoe i and ground [21, 24 and 25]. These forces will act on the crawler shoe bottom surface at a point I [28] as shown in Figure 4. The normal force ($\mathbf{F}_N$)shown in Figure 6 is calculated using the impact function model in MSC ADAMS. In this model, when two solid bodies come in contact with each other a nonlinear spring damper system is introduced to determine the normal force [26, 27, 28 and 29].

$$\mathbf{F}_{N}^{i} = \begin{cases} kx^{e} - c_{\max}\dot{x} * \mathrm{Step}(x,0,0,d,1) & \text{if } x > 0 \\ 0 & \text{if } x \le 0 \end{cases} \tag{17}$$

k – stiffness of the spring = $1 \times 10^{8}\ N$; $m\ x$ – penetration depth = distance variable used in the impact function model; and e – force exponent = 2.0. $c_{\max}$ - maximum damping coefficient $= 1\times 10^{4}\ N - s/m$ and d – penetration depth at which maximum damping is applied = 0.0001 m. The normal force vector acting at point I for the crawler shoe i is $\mathbf{F}_{N}^{i} = \left[F_{N,x}\ \ F_{N,y}\ \ F_{N,z}\right]^{T}$ The coulomb friction model in Adams is used for calculating tangential frictional force ($\mathbf{F}_T$)shown in Figure 6. Based on this model, the frictional force acting at point I is calculated based on equation (18) [21, 25, 28 and 29].

$$\mathbf{F}_{T}^{i} = \mu(\mathbf{V}_{s})\mathbf{F}_{N}^{i} \tag{18}$$

$\mu(\mathbf{V}_{s})$ = friction coefficient defined as a function of slip velocity vector $\mathbf{V}_{s} = [V_{s,x}\ V_{s,y}\ V_{s,z}]$ at contact point I [28, 29]. The friction parameters listed in Table 2 are used in the study for calculating tangential forces.

Table 2 : Friction Parameters used in the study[28, 29]

Static Friction Coefficient (μ_s)	Dynamic Friction Coefficient (μ_d)	Static Transition velocity (V_{st}, m)	Dynamic Transition velocity (V_d, m)
0.4	0.3	0.01	0.1

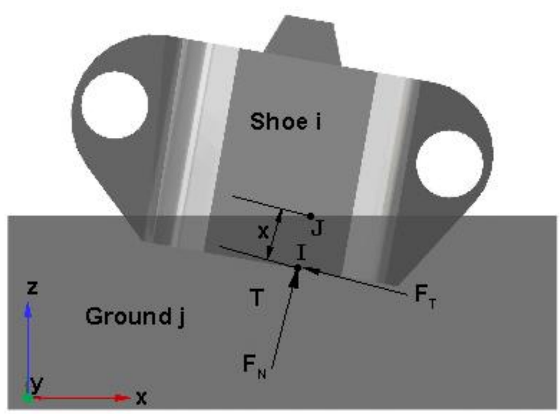

Figure 6 : Normal and Tangential Force and Torque calculations

The tangential force vector at contact point I is given by $\mathbf{F}_{T}^{i} = \left[F_{T,x}\ \ F_{T,y}\ \ F_{T,z}\right]$ The components of the tangential forces $F_{T,x}, F_{T,y}$ and $F_{T,z}$ are calculated by substituting μ obtained from friction coefficient-slip velocity relationship into equation 18 [28, 29]. The friction torque $\mathbf{T}^{i}$ about the contact normal axis shown in Figure 6 impedes any relative rotation of shoe i with respect to the ground [29]. This torque is proportional to the friction force $\mathbf{F}_{T}^{i}$ [29].

$$\mathbf{T}^{i} = \frac{2}{3}R\mathbf{F}_{T}^{i} \tag{19}$$

R = radius of the contact area [29]. The generalized forces associated with contact force vector at point I $(\mathbf{F}_{I}^{i} = \mathbf{F}_{N}^{i} + \mathbf{F}_{T}^{i})$ and torque $\mathbf{T}^{i}$ from Shabana (2010).

$$\mathbf{Q}_{\mathbf{R}}^{i} = \begin{bmatrix} Q_x^i \\ Q_y^i \\ Q_z^i \end{bmatrix} = \mathbf{F}_I^i = \begin{bmatrix} F_{N,x} + F_{T,x} \\ F_{N,y} + F_{T,y} \\ F_{N,z} + F_{T,z} \end{bmatrix} \tag{20}$$

$$\mathbf{Q}_{\theta}^{i} = -\left(\mathbf{A}^i \tilde{\bar{\mathbf{u}}}_I^i \overline{\mathbf{G}}^i\right)^T \mathbf{F}_I^i + (\mathbf{A}^i \overline{\mathbf{G}}^i)^T \mathbf{T}^i \tag{21}$$

$\bar{\mathbf{u}}_I^i = \left[\bar{x}_I^i \;\; \bar{y}_I^i \;\; \bar{z}_I^i\right]^T$ is the position of contact point I on body i with respect to the coordinate system. The generalized forces are added to the generalized external force vector $\mathbf{Q}_e^i$ in equation (1)

Generalized External Forces acting on Oil sand unit i = 15, 16,…, 64: The contact forces, and spring damper forces are the external forces acting on each oil sand unit i as shown in Figure 7. The crawler shoes exert equal and opposite contact forces $(\mathbf{F}_J^i)$ and frictional torque $(\mathbf{T}^i)$ on oil sand unit i at point J as in Figure 7. Consequently, the generalized forces associated with contact force vector $\mathbf{F}_J^i$ and friction torque $\mathbf{T}^i$ on oil sand unit i is given by equations (22) and (23).

$$\mathbf{Q}_{\mathbf{R}}^{i} = \mathbf{F}_J^i = -\mathbf{F}_I^i \tag{22}$$

$$\mathbf{Q}_{\theta}^{i} = -\left(\mathbf{A}^i \tilde{\bar{\mathbf{u}}}_J^i \overline{\mathbf{G}}^i\right)^T \mathbf{F}_J^i + (\mathbf{A}^i \overline{\mathbf{G}}^i)^T \mathbf{T}^i \tag{23}$$

$\bar{\mathbf{u}}_J^i = \left[\bar{x}_J^i \;\; \bar{y}_J^i \;\; \bar{z}_J^i\right]^T$ = position of contact point J on unit i with respect to the body coordinate system shown in Figure 7.

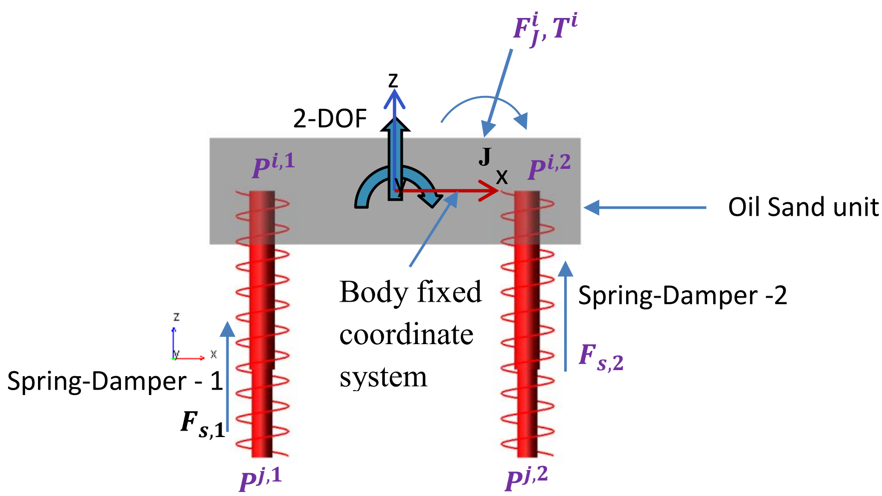

Figure 7 : External forces on Oil Sand unit i

In addition to the contact force, two spring-damper forces are also exerted on the oil sand unit as shown in Figure 7. This spring damper force acts along the line connecting points $P^{i,1}$ and $P^{i,2}$ on oil sand unit i to corresponding points $P^{j,1}$ and $P^{j,2}$ on default ground link of MSC Adams (Figure 7). The spring damper force $F_{s,1}$ acting along the line connecting points $P^{i,1}$ and $P^{j,1}$ from Shabana (2010) can be expressed as in equation (24).

$$F_{s,1} = k(l_1 - l_o) + c\dot{l}_1 \tag{24}$$

k – spring stiffness; c – damping constant; l_1 – length of spring 1 at any time *t;* l_o – undeformed spring length; $\dot{l}$ - time derivative of l_1; and the spring coefficient, damping coefficient and length l_o are listed in Table 3.

Table 3: Oil Sand Properties

Stiffness (*k*), (MN/m)	**Damping (*c*), (kN-s/m)**	**Spring length (l_o), (m)**
20	120	5.0

The generalized forces associated with spring force $F_{s,1}$ can be derived from Shabana (2010) as in equations (25) and (26)

$$\mathbf{Q}^{i}_{\mathbf{R},1} = -F_{s,1}\,\hat{\mathbf{r}}^{ij}_{P,1} \tag{25}$$

$$\mathbf{Q}^{i}_{\theta,1} = F_{s,1}\left(\mathbf{A}^{i}\tilde{\overline{\mathbf{u}}}^{i}_{P,1}\overline{\mathbf{G}}^{i}\right)^{T}\hat{\mathbf{r}}^{ij}_{P,1} \tag{26}$$

$$\hat{\mathbf{r}}^{ij}_{P,1} = \frac{\mathbf{r}^{ij}_{P,1}}{l_1} = \text{ unit vector along the line of action of force } F_{s,1} \tag{27}$$

$$\mathbf{r}^{ij}_{P,1} = \mathbf{r}^{i}_{P,1} - \mathbf{r}^{j}_{P,1} \tag{28}$$

$\mathbf{r}^{\mathrm{i}}_{P,1}$ is the global position vector of point $P^{i,1}$ on oil sand unit I; $\mathbf{r}^{\mathrm{j}}_{P,1}$ is the global position vector of point $P^{j,1}$ on default ground in MSC ADAMS; $\overline{\mathbf{u}}^{i}_{P,1} = \left[\overline{x}^{i}_{P,1}\ \ \overline{y}^{i}_{P,1}\ \overline{z}^{i}_{P,1}\right]$ is the position of contact point $P^{i,1}$ on oil sand unit i with respect to its body coordinate system. Similarly, the generalized forces can be derived for the spring damper-2 system shown in Figure 7. These generalized forces are added to the generalized external force vector I e Q in equation (1).

Generalized Constraint Forces acting on crawler shoe and oil sand unit i: The crawler shoe i is connected to crawler shoe i-1 and i+1 by four joints (two spherical and two parallel primitive joints) as shown in Figure 4. Similarly an oil sand unit i is connected to four adjacent oil sand units by two spherical joints and two inplane primitive joints as defined in the kinematics part of this paper. The generalized constraint forces are obtained using Lagrange multipliers (λ) defined in Shabana [14, 15] and can be expressed in general form as in equation 29.

$$\mathbf{Q}^{i}_{c} = -\mathbf{C}^{\mathrm{T}}_{\mathbf{q}^{i}}\boldsymbol{\lambda} \tag{29}$$

In equation (29), $\mathbf{C} = \mathbf{C}(\mathbf{q},t)$ is the vector of system kinematic constraint equations (both joint and driving constraints) and $\boldsymbol{\lambda}$ is the corresponding vector of system Lagrange multipliers. The number of Lagrange multipliers in the vector $\boldsymbol{\lambda}$ = total number of constraint equations in thevector $\mathbf{C}(\mathbf{q},t) = n_c$ = 346 or 347 as defined in kinematics part of this paper. Substituting the expression for $\mathbf{Q}^{i}_{c}$ into equation (1), the equation of motion for part i is given by equation (30).

$$\mathbf{M}^{\mathrm{i}}\ddot{\mathbf{q}}^{i} + \mathbf{C}^{\mathrm{T}}_{\mathbf{q}^{i}}\boldsymbol{\lambda} = \mathbf{Q}^{i}_{e} + \mathbf{Q}^{i}_{v}\ (i = 2, 3, 4, \ldots\ldots, 64) \tag{30}$$

For n_b = 63 interconnected rigid multi-body system shown in Figure 2, the differential equations of motion can be written from Shabana (2010) as in equation (31).

$$\mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}^{\mathrm{T}}_{\mathbf{q}}\boldsymbol{\lambda} = \mathbf{Q}_{\mathrm{e}} + \mathbf{Q}_{\mathrm{v}} \tag{31}$$

$$\mathbf{M} = \begin{bmatrix} \mathbf{M}^2 & & & \\ & \mathbf{M}^3 & & \mathbf{0} \\ \mathbf{0} & & \ddots & \\ & & & \mathbf{M}^{64} \end{bmatrix};\ \mathbf{C}^{\mathrm{T}}_{\mathbf{q}} = \begin{bmatrix} \mathbf{C}^{\mathrm{T}}_{\mathbf{q}^2} \\ \mathbf{C}^{\mathrm{T}}_{\mathbf{q}^3} \\ \vdots \\ \mathbf{C}^{\mathrm{T}}_{\mathbf{q}^{64}} \end{bmatrix};\ \mathbf{Q}_{\mathrm{e}} = \begin{bmatrix} \mathbf{Q}^{2}_{\mathrm{e}} \\ \mathbf{Q}^{3}_{\mathrm{e}} \\ \vdots \\ \mathbf{Q}^{64}_{\mathrm{e}} \end{bmatrix};\ \textbf{and}\ \mathbf{Q}_{\mathrm{v}} = \begin{bmatrix} \mathbf{Q}^{2}_{\mathrm{v}} \\ \mathbf{Q}^{3}_{\mathrm{v}} \\ \vdots \\ \mathbf{Q}^{64}_{\mathrm{v}} \end{bmatrix} \tag{32}$$

The total number of differential equations in equation (31) is $6 \times n_b = 6 \times 14$ = 378, while the number of unknowns are the sum of $n = 6 \times n_b$ = 378 generalized accelerations and n_c = 346 or 347 Lagrange multipliers. From Shabana (2010), the additional nc equations needed to solve for n + nc unknowns are obtained from kinematic constraint acceleration equation defined in Frimpong and Thiruvengadam (2015) and by equation (33). Equations (31) and (33) can be combined and can be expressed in matrix form as in equation (34).

$$\mathbf{C}_{\mathbf{q}}\ddot{\mathbf{q}} = \mathbf{Q}_{\mathbf{d}} \tag{33}$$

$$\begin{bmatrix} \mathbf{M} & \mathbf{C}^{\mathrm{T}}_{\mathbf{q}} \\ \mathbf{C}_{\mathbf{q}} & 0 \end{bmatrix}\begin{bmatrix} \ddot{\mathbf{q}} \\ \lambda \end{bmatrix} = \begin{bmatrix} \mathbf{Q}_{\mathrm{e}} + \mathbf{Q}_{\mathrm{v}} \\ \mathbf{Q}_{\mathbf{d}} \end{bmatrix} \tag{34}$$

The above system of differential algebraic equations is solved numerically using MSC ADAMS to predict motion parameters and reaction forces.

IV. Solutions to the Dynamic Equations

Adams numerical procedure is verified by solving a simple two-body dynamic problem analytically and comparing the analytical results with the numerical results obtained by solving the same problem with MSC ADAMS. A two-body dynamic problem in which a rectangular block whose dimensions and mass properties are within the same order of magnitude as the crawler shoe is assumed to slide on a flat rectangular terrain. The flat terrain is in turn fixed to the ground. The rectangular block and flat plane interact through contact forces. The objective of this problem is to determine the generalized accelerations, joint reaction forces and driving constraint forces analytically for given initial conditions at time t, as shown in Figure 8.

In this multi-body system, the flat plane and rectangular block are labelled as body 2 and body 3 in Figure 8. respectively. The global and centroidal body coordinate systems are also shown in Figure 8. The dimension of the flat terrain is 30m x 1m x 10m and that of the rectangular block is 0.5m x 0.5m x 3.5 m. The densities of rectangular block and flat terrain are assumed to be same as the density of crawler shoe (Table 1)

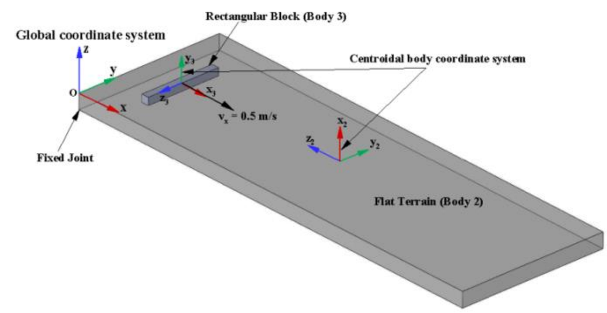

Figure 8 : Schematic of the two body dynamic problem

This two-body system has twelve absolute Cartesian coordinates. The vector of system generalized coordinates from Shabana (2010) is expressed as in equation (35). The absolute velocity vector can be written as equation (36). At time t = 0, the system generalized coordinates and velocity vector are defined by equations (37) and (38).

$$\mathbf{q} = \left[\mathbf{q}^2 \quad \mathbf{q}^3\right]^T = [\mathrm{R}_x^2 \quad \mathrm{R}_y^2 \quad \mathrm{R}_z^2 \quad \phi^2 \quad \theta^2 \quad \psi^2 \quad \mathrm{R}_x^3 \quad \mathrm{R}_y^3 \quad \mathrm{R}_z^3 \quad \phi^3 \quad \theta^3 \quad \psi^3]^T \tag{35}$$

$$\dot{\mathbf{q}} = [\dot{\mathrm{R}}_x^2 \quad \dot{\mathrm{R}}_y^2 \quad \dot{\mathrm{R}}_z^2 \quad \dot{\phi}^2 \quad \dot{\theta}^2 \quad \dot{\psi}^2 \quad \dot{\mathrm{R}}_x^3 \quad \dot{\mathrm{R}}_y^3 \quad \dot{\mathrm{R}}_z^3 \quad \dot{\phi}^3 \quad \dot{\theta}^3 \quad \dot{\psi}^3]^T \tag{36}$$

$$\mathbf{q}(t=0) = [15.0 \quad 5 \quad -0.5 \quad 3\pi/2 \quad \pi/2 \quad \pi/2 \quad 3.25 \quad 5.0 \quad 0.25 \quad 0 \quad \pi/2 \quad 0]^T \tag{37}$$

$$\dot{\mathbf{q}}(t=0) = [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0]^T \tag{38}$$

Body 2 is fixed to the ground using fixed joint as shown in Figure 8 and has zero degrees of freedom. The position and orientation of the centroidal coordinate system of body 2 shown in Figure 8 are fixed with respect to the global coordinate system. The six constraint equations for body 2 can be written as equation (39) from Shabana (2010).

$$C_1(\mathbf{q},t) = R_x^2 - 15.0 = 0$$

$$C_2(\mathbf{q},t) = R_y^2 - 5.0 = 0$$

$$C_3(\mathbf{q},t) = R_z^2 + 0.5 = 0$$

$$C_4(\mathbf{q},t) = \phi^2 - \frac{3\pi}{2} = 0 \tag{39}$$

$$C_5(\mathbf{q},t) = \theta^2 - \frac{\pi}{2} = 0$$

$$C_6(\mathbf{q},t) = \psi^2 - \frac{\pi}{2} = 0$$

The constraint equations for body 2 can be written in a vector form as equation (40) and the corresponding vector of Lagrange Multipliers as equation (41).

$$\mathbf{C}^2(\mathbf{q},t) = [C_1(\mathbf{q},t) \quad C_2(\mathbf{q},t) \quad C_3(\mathbf{q},t) \quad C_4(\mathbf{q},t) \quad C_5(\mathbf{q},t) \quad C_6(\mathbf{q},t)]^T \tag{40}$$

$$\boldsymbol{\lambda}^2 = [\lambda_1 \quad \lambda_2 \quad \lambda_3 \quad \lambda_4 \quad \lambda_5 \quad \lambda_6]^T \tag{41}$$

Body 3 is constrained to move in the x-direction with a constant velocity of 0.5 m/s without changing its orientation. But it can move freely in z and y-directions. The required driving force is assumed to act at the centroid of body 3. The four driving constraint equations for body 3 are given by equation (42). The vector of constraint equations for body 3 is given by equation (43) and the corresponding vector of Lagrange multipliers is also given by equation (44).

$$C_7(\mathbf{q},t) = R_x^3 - 3.25 - 0.5*t = 0$$
$$C_8(\mathbf{q},t) = \phi^3 = 0 \tag{42}$$
$$C_9(\mathbf{q},t) = \theta^3 - \frac{\pi}{2} = 0$$
$$\mathbf{C}(\mathbf{q},t) = \left[\mathbf{C}^2(\mathbf{q},t) \quad \mathbf{C}^3(\mathbf{q},t)\right]^T \text{ or}$$
$$C_{10}(\mathbf{q},t) = \psi^3 = 0$$

$$\mathbf{C}^3(\mathbf{q},t) = \left[C_7(\mathbf{q},t) \quad C_8(\mathbf{q},t) \quad C_9(\mathbf{q},t) \quad C_{10}(\mathbf{q},t)\right]^T \tag{43}$$

$$\boldsymbol{\lambda}^3 = \left[\lambda_7 \quad \lambda_8 \quad \lambda_9 \quad \lambda_{10}\right]^T \tag{44}$$

The vector of system constraint equations and Lagrange multipliers are given by equations (45) and (46). There are twelve absolute coordinates and ten constraint equations and hence the degree of freedom for this simple system is two.

$$\mathbf{C}(\mathbf{q},t) = \left[C_1(\mathbf{q},t) \; C_2(\mathbf{q},t) \; C_3(\mathbf{q},t) \; C_4(\mathbf{q},t) \; C_5(\mathbf{q},t) \; C_6(\mathbf{q},t) \; C_7(\mathbf{q},t) \; C_8(\mathbf{q},t) \; C_9(\mathbf{q},t) \; C_{10}(\mathbf{q},t)\right]^T \tag{45}$$

$$\boldsymbol{\lambda} = \left[\boldsymbol{\lambda}^2 \quad \boldsymbol{\lambda}^3\right]^T = \left[\lambda_1 \;\; \lambda_2 \;\; \lambda_3 \;\; \lambda_4 \;\; \lambda_5 \;\; \lambda_6 \;\; \lambda_7 \;\; \lambda_8 \;\; \lambda_9 \;\; \lambda_{10}\right] \tag{46}$$

The free-body diagram of flat plane (Body 2) and rectangular block (Body 3) is shown in Figures 9 and 10. Due to fixed joint constraints (Figure 9), the orientation of body 2 coordinate system vector with respect to the global coordinate system $\boldsymbol{\theta} = [\phi^2 \; \theta^2 \; \psi^2]^T$ at any time is equal to the initial orientation at $t = 0$. Thus, the time rate of change of $\dot{\boldsymbol{\theta}}^2$ is also equal to zero.

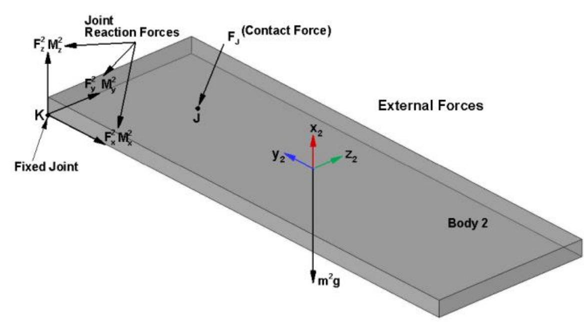

Figure 9: Free-body diagram of flat plane (body 2)

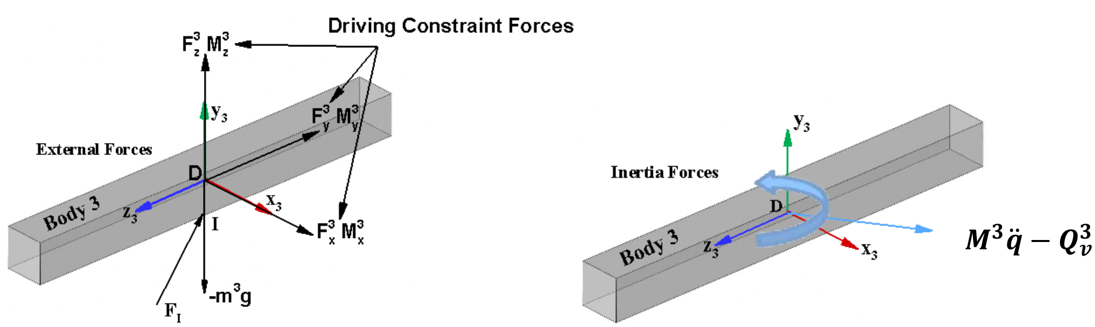

Figure 10 : Free-body diagram of rectangular block (body 3)

Similarly due to driving constraints the orientation of the body 3, $\boldsymbol{\theta}^3 = [\phi^3 \; \theta^3 \; \psi^3]^T$ does not change with time. Therefore, $\boldsymbol{\theta}^3(t) = \boldsymbol{\theta}^3(t=0) = [0 \;\; \pi/2 \;\; 0]^T$ for any given time. Since $\boldsymbol{\theta}^3(t)$ is fixed with respect to time $\boldsymbol{\theta}^{3\cdot}(t) = [0 \;\; 0 \;\; 0]^T$.

The mass inertia matrix of body 2 and body 3 are given in Table 4.

Table 4 : Mass and Inertia tensor of Body 2 and Body 3

Body 2	m^2 **(kg)**	$\bar{\mathbf{I}}^2_{\theta\theta}(kg.m^2)$		
	2.3403 x 10^6	1.95025E+008	0	0
		0	1.75717525E+008	0
		0	0	1.9697525E+007
Body 3	m^3 **(kg)**	$\bar{\mathbf{I}}^3_{\theta\theta}$		
	6825.875	7110.2864583	0	0
		0	7110.2864583	0
		0	0	284.4114583

The rectangular block (body 3) sinks vertically to the ground (body 2) and hence $F_{N,x} = F_{N,y} = 0$. The values of the penetration (x) and penetration velocity (x) in equation (17) to calculate normal force (x) and slip velocities ($\mathbf{V}_s$) in equation (18) to calculate tangential forces ($\mathbf{F}_T$) at any time t are obtained by simulating the schematic model in Figure 8 in MSC ADAMS. These values are shown in Table 5 for t = 0.5s. The friction parameters used in the tangential force calculation are listed in Table 6. It can be seen from Table 5 that the tangential forces $F_{T,y} = F_{T,z} = 0$ since slip velocities in y and z directions, $V_{s,y} = V_{s,z} = 0$.

Table 5 : Contact Force calculation at t = 0.5s using MSC ADAMS

Normal Force (N)		Tangential Force (N)		
Penetration Depth (x), m	Penetration Velocity ($\dot{x}$), m/s	Slip Velocities (m/s)		
		$V_{S,x}$	$V_{S,y}$	$V_{S,z}$
-0.0208	-0.1011	0.5	0	0

Table 6 : Friction Parameters for the Analytical Study [28, 29]

Static Friction Coefficient (μ_s)	Dynamic Friction Coefficient (μ_d)	Static Transition velocity (V_{st}, m)	Dynamic Transition velocity (V_d, m)
0.3	0.1	0.0001	0.01

The contact force vector on body 2 is equal and opposite to that of body 3 as shown in Figure 9 (i.e. $\mathbf{F}^2_J = -\mathbf{F}^3_I$).

The data used to obtain mass matrix $\mathbf{M}$ Jacobian of the kinematic constraints $\mathbf{C_q}$, generalized external forces $\mathbf{Q_e}$ and generalized quadratic velocity vector $\mathbf{Q_e}$ in equation (31) for body 2 and body 3 are listed in Table 7.

Table 7 : Data used in equation (31)

Body 2	$\mathbf{M}^2$	2.340E6	0	0	0	0	0
		0	2.340E6	0	0	0	0
		0	0	2.340E6	0	0	0
		0	0	0	1.9503E8	0	0
		0	0	0	0	1.75718E8	0
		0	0	0	0	0	1.96975E7
	$\mathbf{Q}_e^{2^T}$	0	0	-23002618	0	5091625	0
	$\mathbf{C}_{q^2}$	1	0	0	0	0	0
		0	1	0	0	0	0
		0	0	1	0	0	0
		0	0	0	1	0	0
		0	0	0	0	1	0
		0	0	0	0	0	1
		0	0	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0
	$\mathbf{Q}_v^{2^T}$	0	0	0	0	0	0
Body 3	$\mathbf{M}^3$	6825.875	0	0	0	0	0
		0	6825.875	0	0	0	0
		0	0	6825.875	0	0	0
		0	0	0	7110.28646	0	0
		0	0	0	0	7110.28646	0
		0	0	0	0	0	284.41146
	$\mathbf{Q}_e^{3^T}$	0	0	-23002618	0	5091625	0
	$\mathbf{C}_{q^3}$	0	0	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0
		1	0	0	0	0	0
		0	0	0	1	0	0
		0	0	0	0	1	0
		0	0	0	0	0	1
	$\mathbf{Q}_v^{3^T}$	0	0	0	0	0	0

Using $\mathbf{C}_q = [\mathbf{C}_{q^2} \;\; \mathbf{C}_{q^3}]$ from equation (32) and equation 45,it can be shown that $\mathbf{Q}_d = \mathbf{0}$ in equation 33. The data from Table 7 and $\mathbf{Q}_{d} = \mathbf{0}$ are substituted in to equation 34 and solved for $\ddot{\mathbf{q}}$ and $\boldsymbol{\lambda}$. The results are listed in Tables 8 and 9.

Table 8 : Solution for $\ddot{\mathbf{q}}$

$\ddot{\mathbf{q}}$	$\ddot{R}_x^2$ (m/s^2)	$\ddot{R}_x^2$ (m/s^2)	$\ddot{R}_x^2$ (m/s^2)	$\ddot{\phi}^2$ (d/s^2)	$\ddot{\theta}^2$ (d/s^2)	$\ddot{\psi}^2$ (d/s^2)	$\ddot{R}_x^3$ (m/s^2)	$\ddot{R}_y^3$ (m/s^2)	$\ddot{R}_z^3$ (m/s^2)	$\ddot{\phi}^3$ (d/s^2)	$\ddot{\theta}^3$ (d/s^2)	$\ddot{\psi}^3$ (d/s^2)
	0	0	0	0	0	0	0	0	-3.3236521	0	0	0

Table 8 : Solution for $\ddot{\boldsymbol{q}}$

$\ddot{\boldsymbol{q}}$	$\ddot{R}_x^2$ (m/s^2)	$\ddot{R}_x^2$ (m/s^2)	$\ddot{R}_x^2$ (m/s^2)	$\ddot{\phi}^2$ (d/s^2)	$\ddot{\theta}^2$ (d/s^2)	$\ddot{\psi}^2$ (d/s^2)	$\ddot{R}_x^3$ (m/s^2)	$\ddot{R}_y^3$ (m/s^2)	$\ddot{R}_z^3$ (m/s^2)	$\ddot{\phi}^3$ (d/s^2)	$\ddot{\theta}^3$ (d/s^2)	$\ddot{\psi}^3$ (d/s^2)
	0	0	0	0	0	0	0	0	-3.3236521	0	0	0

Table 9 : Solution for $\boldsymbol{\lambda}$

$\boldsymbol{\lambda}$	λ_1 (N)	λ_2 (N)	λ_3 (N)	λ_4 (Nm)	λ_5 (Nm)	λ_6 (Nm)	λ_7 (N)	λ_8 (Nm)	λ_9 (Nm)	λ_{10} (Nm)
	0	0	-23002618	0	509162.5	0	-4427.5	0	0	-1106.875

Generalized Constraint Forces

Using the vector $\boldsymbol{\lambda}$ in Table 9, the generalized constraint forces for body 2 and body 3 is given by equation (47) from Shabana (2010). These force values are listed in Table 10.

$$\mathbf{Q}_c^2 = \left[\left(\mathbf{Q}_c^2\right)_{\mathbf{R}}^T \quad \left(\mathbf{Q}_c^2\right)_{\mathbf{\theta}}^T \right]^T = -[\lambda_1 \;\; \lambda_2 \;\; \lambda_3 \;\; \lambda_4 \;\; \lambda_5 \;\; \lambda_6]^T$$
$$\mathbf{Q}_c^3 = \left[\left(\mathbf{Q}_c^3\right)_{\mathbf{R}}^T \quad \left(\mathbf{Q}_c^3\right)_{\mathbf{\theta}}^T \right]^T = -[\lambda_7 \;\; 0 \;\; 0 \;\; \lambda_8 \;\; \lambda_9 \;\; \lambda_{10}]^T \tag{47}$$

Table 10 : Generalized Constraint Forces

		$(\mathbf{Q}_c)_R^T$ (N)			$(\mathbf{Q}_c)_\theta^T$ (N-m)		
Body 2	$\mathbf{Q}_c^{2^T}$	0	0	23002618	0	-509162.5	0
Body 3	$\mathbf{Q}_c^{3^T}$	4427.5	0	0	0	0	1106.875

Actual Fixed Joint Forces on body 2

The actual reaction forces $\mathbf{R}^2 = \left[\mathbf{F}^2 \quad \mathbf{M}^2\right]^T$ where $\mathbf{F}^2$ and $\mathbf{M}^2$ are joint reaction forces and moments in the global x, y, and z directions at the fixed joint (point K) shown in Figure 9 for body 2 can be found using generalized constraint forces . From Shabana (2010),

$$\mathbf{F}^2 = \left[F_x^2 \quad F_y^2 \quad F_z^2\right]^T = \left(\mathbf{Q}_c^2\right)_R$$
$$\mathbf{M}^2 = \left[M_x^2 \quad M_y^2 \quad M_z^2\right]^T = -\mathbf{u}_K^2 \times \left(\mathbf{Q}_c^2\right)_{\mathbf{R}} + \left(\mathbf{G}^{2^T}\right)^{-1} \left(\mathbf{Q}_c^2\right)_{\mathbf{\theta}} \tag{48}$$
$$\mathbf{u}_K^2 = \mathbf{A}^2 \bar{\mathbf{u}}_K^2, \bar{\mathbf{u}}_K^2 = \left[-15.0 \quad -5.0 \quad -0.5\right]^T \text{and } \mathbf{G}^{2^T} = \left(\mathbf{A}^2 \overline{\mathbf{G}}^2\right)^T$$

Actual Driving Forces on body 3

Similarly the actual driving forces $\mathbf{D}^3 = \left[\mathbf{F}^3 \quad \mathbf{M}^3\right]^T$ where $\mathbf{F}^3$ and $\mathbf{M}^2$ are driving forces and moments at point D for body 3 (Figure 10) can be obtained from the generalized driving constraint forces3 $\mathbf{Q}_c^3$:

From Shabana (2010), $\left[F^3 \quad F^3 \quad F^3\right]^T \quad \left(\mathbf{Q}^3\right)$

$$\mathbf{M}^3 = \left[M_x^3 \quad M_y^3 \quad M_z^3\right]^T = -\mathbf{u}_D^3 \times \left(\mathbf{Q}_c^3\right)_R + \left(\mathbf{G}^{3^T}\right)^{-1} \left(\mathbf{Q}_c^3\right)_\theta \tag{49}$$
$$\mathbf{u}_D^3 = \mathbf{A}^3 \bar{\mathbf{u}}_D^3 = \mathbf{0} \text{ since, } \bar{\mathbf{u}}_D^3 = [0 \;\; 0 \;\; 0]^T \text{ and } \mathbf{G}^{3^T} = \left(\mathbf{A}^3 \overline{\mathbf{G}}^3\right)^T$$

The fixed joint and driving forces are tabulated in Table 11.

Table 11 : Joint and Driving Forces

	F_x^2 (N)	F_y^2 (N)	F_z^2 (N)	M_x^2 (N-m)	M_y^2 (N-m)	M_z^2 (N-m)
Body 2	0	0	23002618	115013090	-344530107.5	0
Body 3	4427.5	0	0	0	-1106.875	0

The comparison between analytical and simulated values from Adams is summarized in Table 12. The table 12 shows the generalized accelerations on body 2 and body 3, actual reaction forces and moments due to fixed joint on body 2 and driving forces and moments on body 3 at time t = 0.5 s. It can be seen from Table 12, the absolute value of maximum error between the analytical solution and Adams simulated results is within 2%. Hence Adams can be used with confidence for simulating complex multi-body dynamic simulation problems.

Table 12 : Comparison between Analytical and MSC Adams results at t = 0.5s

Quantities	**Body 2**			**Body 3**		
	Analytical	**Adams**	**Error (%)**	**Analytical**	**Adams**	**Error (%)**
a_x (m/s^2)	0	0		0	0	0
a_y (m/s^2)	0	0		0	0	0
a_z (m/s^2)	0	0		-3.3236521	-3.3846	-1.83376
F_x (N)	0	0		4427.5	4383.5822	0.991932
F_y (N)	0	0		0	0	
F_z (N)	23002618	22994000	0.037465	0	0	
M_x (N-m)	115013090	114970000	0.037465	0	0	
M_y (N-m)	-344530107.5	-344410000	0.034861	-1106.875	-1095.5246	1.025446
M_z (N-m)	0	0		0	0	0

The differential algebraic equations (DAE) for the complex crawler-formation interaction given in equation (34) are solved in MSC ADAMS using GSTIFF integrator with I3 formulation [29]. The GSTIFF is a variable-order, variable-step, multi-step integrator based on backward difference formula (BDF). It has maximum integration order of six to calculate solution for the first order ODE's using multi-step predictor-corrector method. The solution methodology for the GSTIFF integrator described below follows the procedure defined in MSC Adams/Solver user manual [29]. In Adams the equations of motion in equation (34) are formulated as

$$\begin{aligned} &\mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}_{\mathbf{q}}^{\mathbf{T}}\boldsymbol{\lambda} = \mathbf{Q}(\mathbf{q}, \dot{\mathbf{q}}, t) \\ &\mathbf{C}(\mathbf{q}, t) = \mathbf{0} \end{aligned} \tag{50}$$

To use GSTIFF integrator equation (50) is converted to first order ODE by introducing a new velocity variable $\mathbf{u} = \dot{\mathbf{q}}$ [29] in equation (50). This substitution results in equation (51).

$$\begin{aligned} &\mathbf{M}(\mathbf{q})\dot{\mathbf{u}} + \mathbf{C}_{\mathbf{q}}^{\mathbf{T}}\boldsymbol{\lambda} - \mathbf{Q}(\mathbf{q}, \mathbf{u}, t) = \mathbf{0} \\ &\mathbf{u} - \dot{\mathbf{q}} = \mathbf{0} \\ &\mathbf{C}(\mathbf{q}, t) = \mathbf{0} \end{aligned} \tag{51}$$

The index of the DAE is defined as the number of time derivatives required to convert DAEs to a system of ODEs [29]. The equation (50) or (51) is in the default Index 3 (I3) formulation of GSTIFF integrator. Equation (51) can also be written in the form of equation (52)

$$\mathbf{F}(\mathbf{y}, \dot{\mathbf{y}}, t) = \mathbf{0} \tag{52}$$

In equation (52) state vector $\mathbf{y} = [\mathbf{u}, \mathbf{q}, \boldsymbol{\lambda}]^T$.

Predictor Step: An explicit predictor step is used to obtain the initial guess value of vector $\mathbf{y}_{n+1}$ at current time t_{n+1} in equation (52). In this step, Taylor series polynomial of given order is fitted using the past values of vector **y** to obtain $\mathbf{y}_{n+1}$.

Corrector Step: The corrector equation for the state vector $\mathbf{y}$ at the current time t_{n+1} can be obtained from backward difference formula [29] as shown in equation (53).

$$\mathbf{y}_{n+1} = \mathbf{y}_n + h\beta_0 \dot{\mathbf{y}}_{n+1} \quad (53)$$

In equation (53) β_0 - constant value specific to the order of backward difference formula and $\dot{\mathbf{y}}_{n+1}$ is obtained from the previous predictor step. Adams solver uses iterative Newton-Raphson numerical procedure for solving newton difference vector $\Delta\mathbf{y}$ arising from linearization of equation (52). Using first order Taylor's series, equation (52) can be linearized about $\mathbf{y} = \mathbf{y}^k$ and $\dot{\mathbf{y}} = \dot{\mathbf{y}}^k$ at current time $\dot{\mathbf{y}} = \dot{\mathbf{y}}^k$ to obtain equations (54) and (55).

$$\mathbf{F}(\mathbf{y}, \dot{\mathbf{y}}, t) = \mathbf{F}\left(\mathbf{y}^k, \mathbf{y}^k, t\right) + \left.\frac{\partial \mathbf{F}}{\partial \mathbf{y}}\right|_{y^k, \dot{y}^k} \left(\mathbf{y} - \mathbf{y}^k\right) + \left.\frac{\partial \mathbf{F}}{\partial \dot{\mathbf{y}}}\right|_{y^k, \dot{y}^k} \left(\dot{\mathbf{y}} - \dot{\mathbf{y}}^k\right) = \mathbf{0} \quad (55)$$

$$\mathbf{F}\left(\mathbf{y}^k, \dot{\mathbf{y}}^k, t\right) + \left.\frac{\partial \mathbf{F}}{\partial \mathbf{y}}\right|_{y^k, \dot{y}^k} \Delta\mathbf{y} + \left.\frac{\partial \mathbf{F}}{\partial \dot{\mathbf{y}}}\right|_{y^k, \dot{y}^k} \Delta\dot{\mathbf{y}} = \mathbf{0} \quad (56)$$

Using equation (53), equation (56) can be derived as follows:

$$\mathbf{y} - \mathbf{y}^k = \Delta\mathbf{y} = h\beta_0\left(\dot{\mathbf{y}} - \dot{\mathbf{y}}^k\right) = h\beta_0\left(\Delta\dot{\mathbf{y}}\right) \quad (56)$$

$$\therefore \quad \Delta\dot{\mathbf{y}} = \frac{1}{h\beta_0}\Delta\mathbf{y}$$

Substituting equation (56) into equation 55 results in equation (57)

$$\left[\left.\frac{\partial \mathbf{F}}{\partial \mathbf{y}}\right|_{\mathbf{y}^k, \dot{\mathbf{y}}^k} + \frac{1}{h\beta_0}\left.\frac{\partial \mathbf{F}}{\partial \dot{\mathbf{y}}}\right|_{\mathbf{y}^k, \dot{\mathbf{y}}^k}\right]\Delta\mathbf{y} = -\mathbf{F}\left(\mathbf{y}^k, \dot{\mathbf{y}}^k, t\right) \quad (57)$$

From equations (51), (52) and (57), equation (58) can be derived as follows:

$$\frac{\partial \mathbf{F}}{\partial \mathbf{y}} = \begin{bmatrix} -\mathbf{Q_u} & \mathbf{M_q}\dot{\mathbf{u}} + \mathbf{C}_{\mathbf{qq}}^T\boldsymbol{\lambda} - \mathbf{Q_q} & \mathbf{C}_{\mathbf{q}}^T \\ \mathbf{I} & 0 & 0 \\ 0 & \mathbf{C_q} & 0 \end{bmatrix} \text{ and } \frac{\partial \mathbf{F}}{\partial \dot{\mathbf{y}}} = \begin{bmatrix} \mathbf{M} & 0 & 0 \\ 0 & -\mathbf{I} & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (58)$$

Substituting equation (58) into equation (57), equation (59) is obtained as follows:

$$\begin{bmatrix} \dfrac{\mathbf{M}}{h\beta_0} - \mathbf{Q_u} & \mathbf{M_q}\dot{\mathbf{u}} + \mathbf{C}_{\mathbf{qq}}^T\boldsymbol{\lambda} - \mathbf{Q_q} & \mathbf{C}_{\mathbf{q}}^T \\ \mathbf{I} & -\dfrac{\mathbf{I}}{h\beta_0} & 0 \\ 0 & \mathbf{C_q} & 0 \end{bmatrix}_{\mathbf{y}^k, \dot{\mathbf{y}}^k} \Delta\mathbf{y} = -\mathbf{F}\left(\mathbf{y}^k, \dot{\mathbf{y}}^k, t\right) \quad (59)$$

Equation (59) is then solved iteratively using Newton-Raphson algorithm until solution is converged for the current time t_{n+1}.

Convergence: When the value of residue ($|\mathbf{F}|$) and corrections $|\Delta\mathbf{y}|$ in equation (59) is small, the GTSTIFF integrator in MSC Adams estimates local integration error which is a function of difference between the predicted and corrected value, step size h and the order of integration [29]. When this integration error is less than the specified integration error tolerance in MSC Adams (specified error = 1.0E-003), the solver proceeds to the next time step. Otherwise the integrator takes a smaller time step and recalculates the solution. This predictor-corrector process is repeated until the simulation end time is reached.

Stability: It can be seen in equation (59) when step size h approaches zero the Jacobian matrix in equation (59) becomes singular. Hence GSTIFF integrator with I-3 formulation becomes unstable at small time steps and hence an alternative formulation that reduces the index of DAEs has to be used. The GSTIFF integrator with SI2 (Stabilized Index - 2) formulation modifies 22 equation

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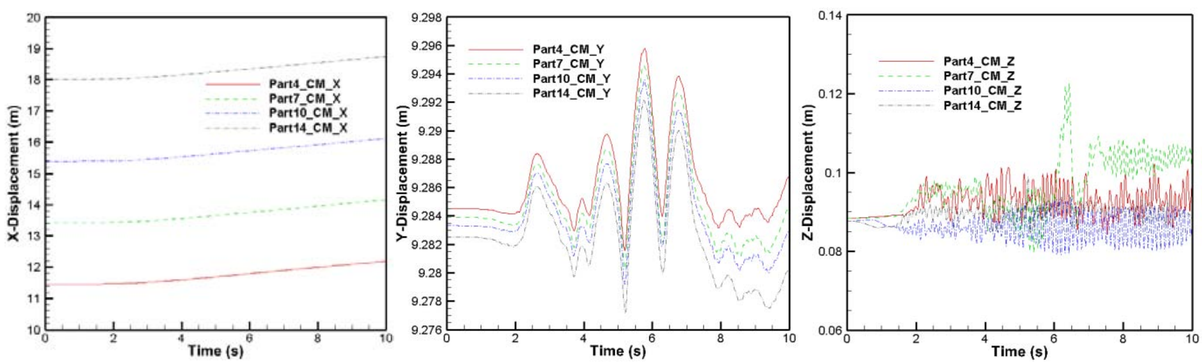
(51) to DAEs with Index 2. This modification stabilizes the DAEs and eliminates the singularity of the SI2 Jacobian matrix when step size h is closer to zero [29].

V. Results and Discussions

The crawler track assembly in Figure 2 is modeled in SOLIDWORKS 2013 and the solid model is imported into MSC ADAMS. A 3-D virtual crawler track interacting with oil sands is created in MSC ADAMS to simulate the dynamic propel action of the crawler track for two types of motion constraints. It should be noted that before any propelling operation begins, the oil sand model along with crawler track is allowed to reach its static equilibrium position. From the equilibrium position, the simulation experiment for the 10s period of straight line and turning motion of crawler track on oil sand ground have been carried out to study the linear and angular motion of crawler track, contact forces between crawler shoes and ground and deflection of the *oil sand terrain.* In this paper, only the kinematics (displacement, velocity and accelerations) of crawler shoes are presented. The dynamic results (contact forces, constraint forces and total deformation of oil sand) are presented separately in the force part of this paper.

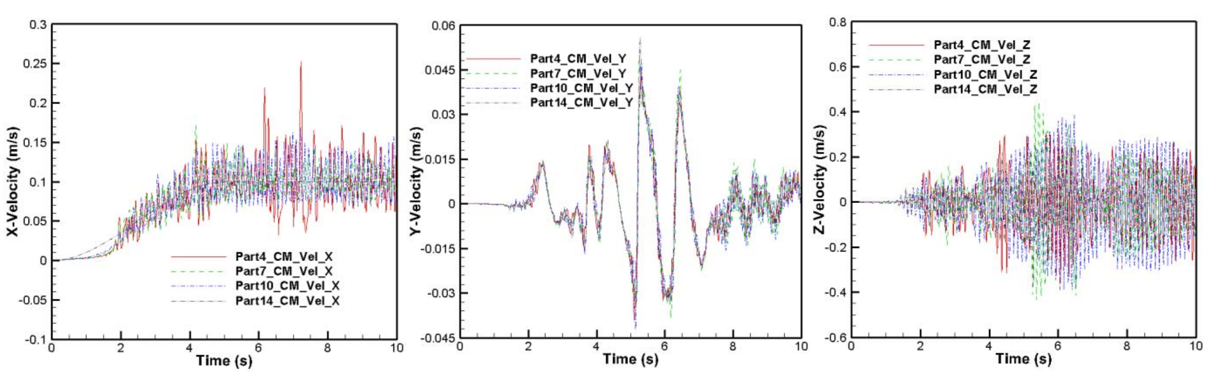
Case 1: Only Translation: The time variation of displacement of center of mass of different crawler shoes in the x, y and z-direction is plotted and is shown in Figure 11. The x-displacement (Figure 11a) follows the motion constraint imposed on crawler shoe 13 while the y and z displacement are determined based on the external forces acting on each crawler shoes during the translation motion. The y-displacement (Figure 11b) shows negligible sliding motion of the crawler track while the time variation of displacement in the z-direction (Figure 11c) shows the vertical bouncing motion from its equilibrium position at time t = 0.



(a) (b) (c)

Figure 11 : Displacement of different crawler shoes

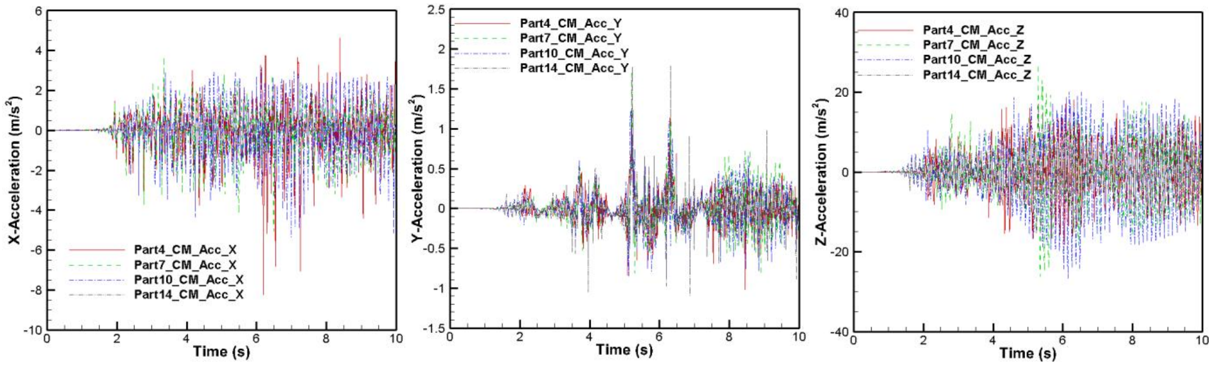
The time variation of velocity of different crawler shoes in the x, y and z directions are shown in Figure 12. The x - velocity variation in Figure 12a shows that with the exception of part 14, all other shoes have fluctuating x - velocity variation in time during their translation motion. This is because the longitudinal driving constraint is only applied on part 14 while other crawler shoes x-velocity behavior are also influenced by external and joint forces. The lateral sliding velocity (y-velocity) is the same for all crawler shoes as shown in Figure 12b. The vertical velocity 23 (Figure 12c) also shows fluctuating behavior due to vertical bouncing of crawler track during its propelling motion.



(a) (b) (c)

Figure 12 : Velocity of different crawler shoes

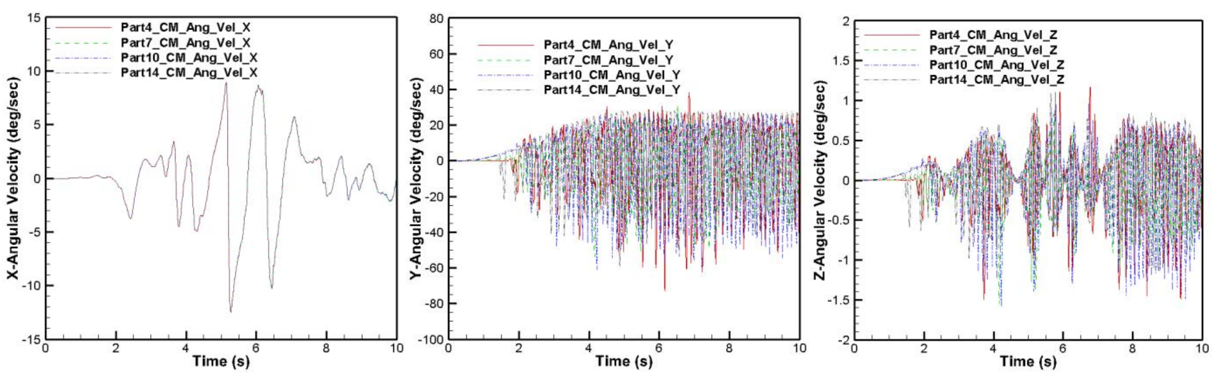
The accelerations of different crawler shoes in x, y and z-directions is shown in Figure 13. The acceleration of part 14 in the x-direction is dictated by the driving constraint (maximum acceleration on part 14 is 0.03 m/s2), while other parts have large fluctuations in their values as shown in Figure 13a. The magnitude of acceleration in the y-direction is much smaller in comparison to their values in z-direction as shown in Figures 13b and 13c.



(a) (b) (c)

Figure 13 : Acceleration of different crawler shoes

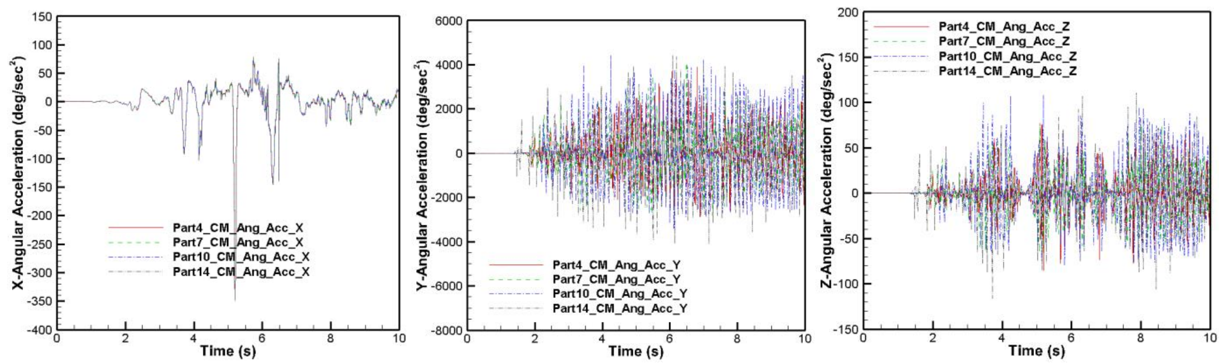
Figure 14 shows the variation of angular velocities in x, y and z directions. It can be seen from Figure 14a that all crawler shoes have same angular velocity variation with time in x-direction and hence the whole crawler track rolls about the x-axis during its propeling motion. This rolling angular velocity attains its peak value when the crawler track attains its specified x-translation velocity (Figure 12a) and decreases thereafter as shown in Figure 14a. The crawler shoes also rotates about y-axis (joint axis) with large varying angular velocity (Figure 14b) causing relative rotational motion between adjacent shoes of the crawler track. The crawler track also experiences small fluctuating rotational velocities along the global z-direction with average value approximately equal to zero as shown in Figure 14c. This rotation velocity causes crawler track to slide left or right from its direction of motion.



(a) (b) (c)

Figure 14 : Angular velocity of different crawler shoes

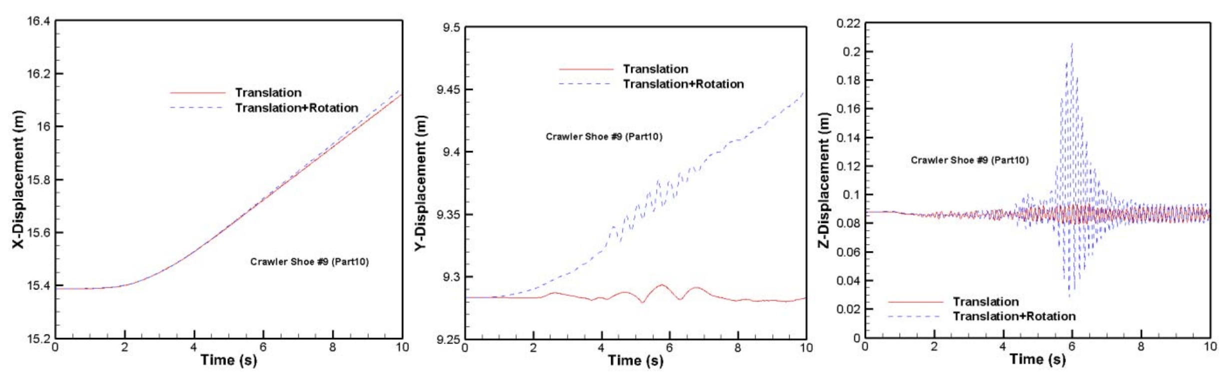
The time variation of angular accelerations about x, y and z-axes is shown in Figure 15. It can be seen that the whole crawler track rolls back and forth with varying x- angular acceleration as shown in Figure 15a. Due to the fluctuating rotational velocity arising from equivalent revolute joint, the crawler shoes also have unsteady angular acceleration variation about y-axis (Figure 15b). The angular acceleration variation in z-direction (Figure 15c) shows that its average value is approximately zero and hence the crawler track will maintain its straight line motion.



(a) (b) (c)

Figure 15 : Angular acceleration of different crawler shoes

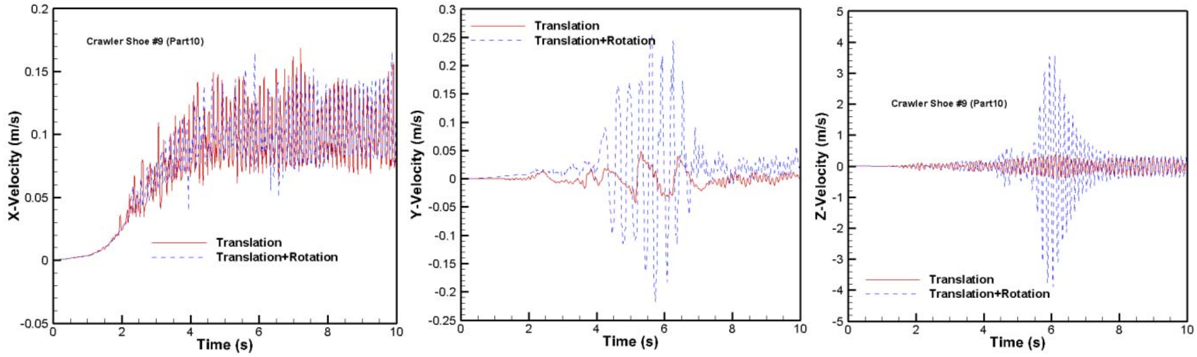
Case 2 – Translation and Rotation: In this case the shovel translates and turns with a prescribed velocity as discussed in kinematics part of this paper. Due to space limitations, only results obtained for crawler shoe 9 (Part 10) is plotted and compared with the corresponding results from translation only motion type. The comparison results for other crawler shoes will follow the same general behavior. The time variation of displacement of center of mass of part 10 in x, y and z – directions is shown in Figure 16. Due to the same translation driving constraint, the x-displacement overlaps with each other. The y-displacement increases due to the sliding action of the crawler track arising from the imposed turning motion. The z-displacement for both motion type exhibits similar behavior except during the middle of the turning motion (between 4.0 – 7.0 s) where the z-displacement show large unsteady behavior as shown in Figure 16c.



(a) (b) (c)

Figure 16 : Displacement of crawler shoe 9

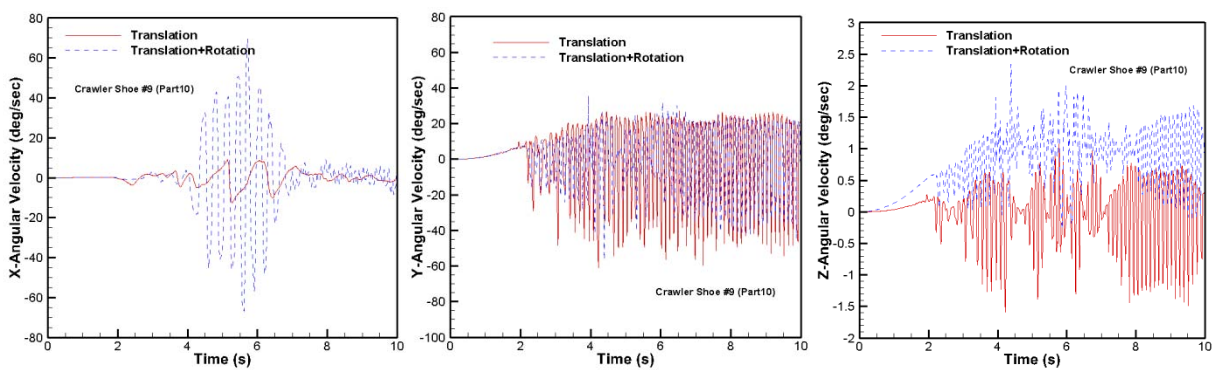
The time variation of velocities in x, y and z directions for crawler shoe 9 for the case of translation and turning motion is shown in Figure 17. The x-velocity variation show similar behavior for both motion types as shown in Figure 17a. The y-velocity (Figure 17b) shows large fluctuations during the middle of the turning motion when compared with translation motion type. This is due to the irregular increase in the lateral displacement of the crawler track (y-displacement in Figure 16b) when the crawler is turning at its prescribed maximum velocities. The unsteady lateral sliding coupled with the flexibility of the oil sand unit causes large amplitude in z-displacement (Figure 16c) and z-velocity (Figure 17c) distributions. This unsteady motion is brought back to the oscillating steady behavior in less than 3 seconds as shown in Figures 16c, 17b and 17c due to the large damping characteristic of the oil sand terrain.



(a) (b) (c)

Figure 17 : Velocity of crawler shoe 9

The comparison of time variation of acceleration in x, y and z directions for crawler shoe 9 for both motion types reveal similar general behavior as shown for velocity distributions in Figure 17 and hence not plotted. The angular velocity variation for crawler shoe 9 is shown in Figure 18. The bouncing action of the crawler track also produces simultaneous rolling motion as shown by the angular velocity distribution about x-axis in Figure 18a. But turning motion exhibits increased rolling behavior when compared with translation motion due to the unsteady lateral sliding of the crawler track. The angular velocity in y-direction shows similar fluctuating behavior for both motion types while the angular velocity about z-axis for turning motion follows the rotation motion constraint (1.0 deg/s) imposed on the moving z-axis of the body fixed motion coordinate system on part 14. The angular acceleration comparison for both motion types also shows similar unsteady behavior as angular velocity (Figure 18) and hence not plotted here.



(a) (b) (c)

Figure 18 : Angular Velocity of crawler shoe 9

VI. Conclusions

The dynamic equation of motion governing the multi-body model of crawler track assembly is obtained to study the propelling motion of crawler track on the oil sand terrain. A simple two-body contact dynamic problem is simulated in MSC Adams and the simulation results for accelerations and constraint forces at a given time is verified by solving the same problem analytically using the dynamic equations of motion and comparing the analytical solution to the simulation results. Subsequent to analytical verification, a rigid 3D virtual prototype model of the crawler track interacting with the oil sand terrain is developed and simulated in ADAMS environment. The simulation is carried out for the prescribed translation and rotation motion constraints on one of the crawler shoes in the track as reported in the kinematics part of this paper. The interaction between each crawler shoe and ground is modeled using contact force formulation in MSC ADAMS. The kinematic simulation results of the crawler track propelling on the ground for both driving constraints show that in 10 s the crawler slips forward for a maximum longitudinal distance of 0.75 m with vertical bouncing, lateral sliding and rotation about the x, y and z-axes. For translation motion, the maximum values of lateral sliding and vertical bouncing are 1 cm and 3.5 cm from the equilibrium position. The corresponding maximum sliding and bouncing velocities and accelerations are 0.06 m/s and 0.45 m/s and 1.8 m/s2 and 27 m/s2. The maximum magnitude of angular velocities and accelerations attained about the three orthogonal axes are 12.5 deg/s, 73.0 deg/s and 1.6 deg/s and 350 deg/s2, 4420 deg/s2 and 115 deg/s2. For turning motion, these values are 0.5 m and 0.15 m; 0.328 m/s and 4 m/s; and 16 m/s2 and 290 m/s2 for lateral and vertical displacement, velocities and accelerations. The maximum magnitude of angular velocities and accelerations about the x, y and z-axes are 70 deg/s, 225 deg/s and 7 deg/s; and 3150 deg/s2, 20176 deg/s2, and 350 deg/s2.

References Références Referencias

1. Joy Global Inc., 4100C BOSS Electric Mining Shovel - AC Drive Product Overview, 1-8, 2012. http://www.phmining.com/MinePro/Literature/Brochures/SUR_4100C_BOSS_AC_BRO_XS-5491.pdf
2. P&H. 2005. Peak Performance Practices: Lower Works, © P&H MinePro, Milwaukee, WI
3. Nakanishi, T. and A.A.Shabana. 1994. Contact forces in the nop-linear dynamic anlysis of tracked vehicles, Int. J. for Numerical Methods in Engineering, Vol., 37: 1251-1275.
4. Choi, J.H., Lee, H.C. and A.A. Shabana. 1998. Spatial dynamics of multibody tracked vehicles. Part I: Spatial equations of motion. Vehicle Systems Dynamics, Vol. 29: 27-49.
5. Lee, H.C., J.H.Choi and A.A.Shabana. 1998. Spatial dynamics of multi-body tracked vehicles II: Contact forces and simulation, Vehicle Systems Dynamics, Vol. 29: 113-137.
6. Rubinstein, D. and R.Hitron. 2004. A detailed multi-body model for dynamic simulation of off-road tracked vehicles, Journal of Terramechanics, 41: 163-173.
7. Rubinstein, D., and A.Coppock. 2007. A detailed single-link track model for multi-body dynamic simulation of crawlers, Journal of Terramechanics, 44: 355-364.
8. Ferrati, G., and R.Girelli. 1999. Modeling and simulation of an agricultural tracked vehicle, Journal of Terramechanics, 36: 139-158.
9. Ryu, H.S., D.S.Bae, J.H.Choi, and A.A.Shabana. 2000. A compliant track link model for high-speed, high-mobility tracked vehicles, Int. J. Numer. Meth. Engng, 48: 1481-1502.
10. Madsen, J. 2007. High fidelity modeling and simulation of tracked elements for off-road applications using MSC/ADAMS. http://sbel.wisc.edu/documents/Independent%20Study%20Report%20final%20edit.pdf
11. Ma, Z. D. and N.C.Perkins. 1999. A hybrid track model for studying dynamic track/sprocket Contact, Proceedings of the ASME Noise Control and Acoustics Division: 147-155.
12. Frimpong, S., Y.Hu, and K.Awuah-Offei. 2005. Mechanics of cable shovel-formation interactions in surface mining excavations, Journal of Terramechanics 42: 15-33.
13. Frimpong, S., and Li, Y. 2007. Stress loading of the cable shovel boom under in-situ digging conditions, Engineering Failure Analysis 14: 702-715.
14. Shabana, A. A. 2010. Computational dynamics, 3rd Edition, John Wiley & Sons, NY.
15. Shabana, A. A. 1998. Dynamics of multi-body Systems, 2nd Edition, Cambridge Univ. Press.
16. Edward, J. H. 1989. Computer aided kinematics and dynamics of mechanical systems. Allyn and Bacon Series in Engineering.
17. Schiehlen, W., N.Guse and R.Seifried. 2006. Multibody dynamics in computational mechanics and engineering applic., Comput. Methods Appl. Mech. Engrg. 195: 5509-5522.
18. JOY Global Inc.
19. Nakanishi, T. and Shabana, A. A., Contact forces in the nop-linear dynamic anlysis of tracked vehicles, Int. J. for Numerical Methods in Engineering, Vol., 37, 1251-1275 (1994).
20. Choi, J.H., Lee, H.C. and Shabana, A. A., Spatial dynamics of multibody tracked vehicles Part I: Spatial equations of motion.
21. Lee, H.C., Choi, J.H. and Shabana, A. A., Spatial dynamics of multi-body tracked vehicles Part II: Contact forces and simulation results
22. Hibbeler, R. C., Engineering mechanics, dynamics, 1989, 5th Edition, Macmillan
23. Bedford, A. and W.Fowler. 2002. Eng. Mechanics: Statics and Dynamics. Prentice Hall.
24. Wong, J.Y., Theory of Ground Vehicles, 2001, 3rd Edition, John Wiley & Sons, Inc
25. Frimpong, S., Li, Y. and Suglo, R., 2013, Dynamic torque and soil deformation mechanics and simulation of the GAP machinery, J Powder Metall Min S1:002.
26. Lindberg , D., MSC Adams modeling of mechanical system in A400M crew Entrance Door, Master Thesis, Linkoping Institue of Technology, Sweden, 2012.
27. Kong, D., Meagher, J.M., Xu, C., Wu, X. and Wu, Y., "Nonlinear contact analysis of gear teeth for malfunction diagnostics," Proceedings of the IMAC 26th Conference on Structural Dynamics, Society for Experimental Mechanics, Orlando, Fla, USA, February, 2008.
28. MSC. 2014. MSC ADAMS/View help document. © MSC Corporation, San Diego, CA.
29. MSC. 2014. MSC ADAMS/Solver help document. © MSC Corporation, San Diego, CA.

30. Frimpong, S., and Thiruvengadam, M. 2015. Rigid multi-body kinematics of shovel crawler-formation interaction, Submitted to Engineering Failure Analysis.__

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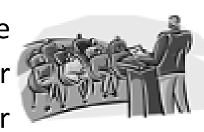

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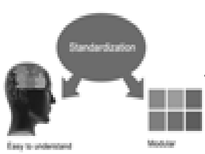

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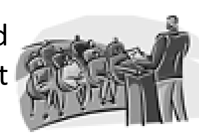

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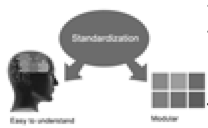

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- Paper Title should be of Font Size 24 with one Column section.
- Author Name in Font Size of 11 with one column as of Title.
- Abstract Font size of 9 Bold, “Abstract” word in Italic Bold.
- Main Text: Font size 10 with justified two columns section
- Two Column with Equal Column with of 3.38 and Gaping of .2
- First Character must be three lines Drop capped.
- Paragraph before Spacing of 1 pt and After of 0 pt.
- Line Spacing of 1 pt
- Large Images must be in One Column
- Numbering of First Main Headings (Heading 1) must be in Roman Letters, Capital Letter, and Font Size of 10.
- Numbering of Second Main Headings (Heading 2) must be in Alphabets, Italic, and Font Size of 10.

You can use your own standard format also.
Author Guidelines:

1. General,

2. Ethical Guidelines,

3. Submission of Manuscripts,

4. Manuscript’s Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

1. GENERAL

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Complete support for both authors and co-author is provided.

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Original research paper: Such papers are reports of high-level significant original research work.

Review papers: These are concise, significant but helpful and decisive topics for young researchers.

Research articles: These are handled with small investigation and applications

Research letters: The letters are small and concise comments on previously published matters.

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The recommended size of original research paper is less than seven thousand words, review papers fewer than seven thousands words also.Preparation of research paper or how to write research paper, are major hurdle, while writing manuscript. The research articles and research letters should be fewer than three thousand words, the structure original research paper; sometime review paper should be as follows:

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(a)Title should be relevant and commensurate with the theme of the paper.

(b) A brief Summary, "Abstract" (less than 150 words) containing the major results and conclusions.

(c) Up to ten keywords, that precisely identifies the paper's subject, purpose, and focus.

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(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, unless non-standard.

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(g) Discussion should cover the implications and consequences, not just recapitulating the results; conclusions should be summarizing.

(h) Brief Acknowledgements.

(i) References in the proper form.

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

Search engines for most searches, use Boolean searching, which is somewhat different from Internet searches. The Boolean search uses "operators," words (and, or, not, and near) that enable you to expand or narrow your affords. Tips for research paper while preparing research paper are very helpful guideline of research paper.

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- One should avoid outdated words.

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Acknowledgements: Please make these as concise as possible.

References

References follow the Harvard scheme of referencing. References in the text should cite the authors' names followed by the time of their publication, unless there are three or more authors when simply the first author's name is quoted followed by et al. unpublished work has to only be cited where necessary, and only in the text. Copies of references in press in other journals have to be supplied with submitted typescripts. It is necessary that all citations and references be carefully checked before submission, as mistakes or omissions will cause delays.

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27. Refresh your mind after intervals: Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

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30. Think and then print: When you will go to print your paper, notice that tables are not be split, headings are not detached from their descriptions, and page sequence is maintained.

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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 criterion for grading the final paper by peer-reviewers.

Final Points:

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

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- Separating a table/chart or figure - impound each figure/table to a single page
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· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

· Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives

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- Fundamental goal
- To the point depiction of the research
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- Significant conclusions or questions that track from the research(es)

Approach:

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- What you account in an conceptual must be regular with what you reported in the manuscript
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- Explain the value (significance) of the study
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- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
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Approach:

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- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

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- Report the method (not 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 - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in 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 a 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. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise 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 in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to 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 part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a 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 implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly 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 with prospect, and let it drop at that.

- Make a decision if each premise is supported, 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 the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One 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 available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

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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

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