Regression Analysis of the Suspension System by using MINITAB

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Abstract— The vehicle's suspension system performs many tasks like isolating the vehicle's chassis from vibrations and road crashes also it maintains the contact between the tire and the road and. The most important element is the suspension system, which has a significant impact on the behaviour and driving quality of the vehicle. An important part of the research has focused on improving the performance of the suspension system by modifying the damping factor to change the frequency response of the system. Depending on the dynamic characteristics of the car suspension system, this work uses a modern analysis concept in the suspension system. The author puts technique to forecast the performance characteristics, which provides more techniques to further improve the performance of suspension system. The author uses the output Regression model of MINITAB. Through the Regression model performance of suspension system model can be predict. It achieved the forecasting of the behaviour of the suspension system model with different loading condition.

Key words: Suspension System; MINITAB; Regression Analysis

I. INTRODUCTION

Traditionally, suspension system execute the number of task like managing the contact between automobile tire and the road ,to make the stability of the vehicle, and dividing the frame of the vehicle from road-induced vibration and shocks. That's why ride will be comfort.

In general, Comfort ride, road handling, and consistence are the most important factors to execute suspension performance. Comfort ride is proportional to the quickening acceleration of the automobile body, while handling with the road is linked to the relative dislocation between automobile body and the tires. On the other hand, consistence of automobile is related to the contact of tire. The main problem with suspension design and control is that now the improvement of these three goals is a challenge, because these goals may conflict with each other in the vehicle's operational area.

In the case of large off-road vehicles, the extremes in operating conditions to which the vehicle suspension system is exposed make this conflict even greater. Vehicles must be able to travel easy and rough ride including steep hills, ditches, and boulder, as well as relatively smooth surfaces such as paved roads and highways.

The suspension system for the off road vehicle faced many challenges include the higher damp forces run into with heavy vehicles moving over rough terrain, the costs of producing large shock absorbers, and the unique requirements of control systems that must operate under widely varying conditions and vehicle configurations.

According to its setup, suspension systems can be divided into two ways: either they are solid axle suspension system or either they are independent suspension system. Each group can be functionally quite different (Gillespie, 1992) [1], and they are studied and discussed accordingly.

1) In a solid axle suspension, the motion and trembling of one wheel are transfer to the opposite wheel directly.
2) In an independent suspension on the other hand, the motion of every wheel is independent of the other wheel.

According to the level of controllability, suspension systems are classified as passive, active, or semi-active suspension. Aside from the inherent advantages and disadvantages of each type, all of them in some way utilize the spring and damper units.

Passive suspensions are the most commonly used systems in most vehicles. These systems are collected from springs and dampers with established properties. The main elements of passive suspension systems are wheels with tires, wheel transport systems, spring and shock elements, steering and brakes.

In mostly cases, active suspension systems use hydraulic actuators to generate the desired force. These systems are controlled and managed by an external power source. Although active elements check the reactions of vertical suspension forces, they do not check kinematics. Despite the excellent performance of these systems, the high energy consumption, size, weight and cost of active suspension systems is a serious problem.

Semi-active suspension systems may include dampers and springs. However, the properties of these components (stiffness and damping) can be controlled and regulated in real time outside. These properties can be controlled by providing an electrical signal or other type of external power supply to the system. Semi-active systems are a compromise between active and passive systems.

Hence, an important fact is that the required transaction between comfort ride and safety ride is also determined for mechatronic suspension systems although the tuning parameters for the adjustment of the suspension setting change from the choice of the passive suspension component to the choice of the parameterization of the suspension controller.

The most important benefit of mechatronic suspension systems is the flexibility provided by the actuator components.

In order to measure vehicle's comfort, vehicle vibrations can be measured in two ways: vertical (i.e. Movement) and horizontal (i.e. Rotation). The most commonly used measurement method is the acceleration of RMS. It can be define as:

With (*T*) being the total sample time, *(a)* the sprung mass acceleration, and *t* the time. This measurement must be performed for both directions. However, to simplify the measurement, just the body vertical acceleration (i.e. heave) is often measured. In this study, to assess the riding comfort of vehicle, RMS accelerations in the vertical and horizontal directions were measured. With the purpose of considering the factor of vibration frequency in ride comfort measurement, a weighted form of accelerations can be used in equation 2-1 instead of the plain acceleration. In this method, a weighting curve, which is created base on the human sensitivity of different vibration frequencies, determines a weighting factor for the amplitude of each acceleration data respect to the frequency of this acceleration data. More detail in this subject can be found in the reference of (Thoresson, 2003) [1]. In another method, with the aim of considering the frequency factor, the acceleration data of the sprung mass is filtered by a Human Response Filter (i.e. HRF) (Donahue, 1998) [2].

Essentially, the mentioned RMS acceleration formulation is used to assess the ride comfort capability of the suspension systems. The focus of some studies is the human exposure to the vehicle vibrations. For these studies, other methods are needed to involve some related variables in measurement of ride comfort. The important variables are the magnitude, frequency, direction, and duration of vibrations. For example, There are some standards defined concerning with the measurement of ride comfort of agricultural vehicles and the acceptable levels of the acceleration transmitted to their operators. Among them two ISO standards are usually preferred for the agricultural vehicles (Adams, 2002) [3].

The first standard is ISO 2631, which was initially issued in 1974. This standard is a general norm used for three main issues of vibration measurement, human exposure to the whole body vibration, and acceptable vibration levels relative to the health risk (Pickel P., 1993) [4]. In this standard, a vector is used as the weighed factor for evaluating the total load, which contains the loads of vibrations in all three linear directions (Hansson P. A., 1995) [5]. In addition, this standard considers the factor of time limitation in order to define the acceptable vibration levels of human.

Another standard is ISO 5008 issued initially in 1974. This standard describes the method of measuring and analyzing the tractor driver's vibration load (Hansson P., 1995) [6]. This standard presents a rough and a smooth test-track, which are designed in order to imitate normal driving conditions in agricultural applications. Standard makes use of the ISO2631/1 standard in order to weight the frequency information of accelerations. Then, it integrates the values overall frequencies in order to form a single root mean square (RMS) value for acceleration (Adams, 2002) [2].

Handling is a feature of a vehicle that provides a stable and safe ride, which can be achieved by continuous contact between the tires and the road surface. In some references, handling is also caused by other names such as road holding, ride stability and driving safety, which means the same meaning. The handling of a vehicle is important during manoeuvring such as cornering, braking or acceleration. In these situations, improper handling can affect the passenger safety. As such, handling is considered an important ability for vehicles and, in addition to convenience of ride comfort, is considered the main purpose of suspension applications in vehicles.

Handling is related to the tire contact force that is influenced by two factors: wheel and vehicle body vibrations. Vertical motion of the wheels is affected mainly by road roughness, and body motions are produced mainly by vehicle directional changing. The manoeuvring changing of vehicles is considered as the major challenge for the handling characteristic of a vehicle. For example during cornering, the centrifugal forces push vehicles. This must be resisted by the tire contact forces. In the same time, the centrifugal force causes load shift on the tires from one side of the vehicle to another side. This leads to major reduction in the tire contact forces and provides consequently a poor handling performance. Likewise, as a vehicle brakes or accelerates rapidly, a critical handling state is created. In this condition, extra traction forces on the tires are needed, whereas because of the weight transfer from back to front or conversely, tire contact force cannot be created optimally.

The handling capability of a vehicle is affected by different characteristics of the vehicle. The main one is the characteristic of the vehicle suspension. A good suspension provides strong resistance to the vehicle body motion (i.e. roll, pitch and heave) and prevents excessive weight transfer in the vehicle body, which increase the vertical loads of the wheels and affects the handling negatively. In addition, an effective suspension can control the vertical vibration of the wheels (i.e. wheel hop), which are produced by the road roughness and have direct influence on the tire contact force and consequently on handling of the vehicle.

As mentioned above, vehicle handling and ride comfort are the two main functions of the vehicle suspension. In order to evaluate a suspension system, these two characteristics must be measured and examined. Unlike ride comfort, which was explained before, there is no standard to quantify or formulate the vehicle handling. This makes the qualification of the handling complicated. However, there are some methods for indirect measurement of handling. Good handling can be provided by stable tire contact forces, and high variation of the tire force reduces the handling capability of the vehicles.

As a result, variation of the contact force between the tires and road surface corresponds directly to the vehicle handling, and it can be used for the quantification. The term of tire contact force is equal to the vertical tire force. As a result, the tire force variation or dynamic tire force can be used in order to measure the handling. Lower dynamic tire force means better handling and higher dynamic tire force indicates worse handling. In experimental works, the direct measurement of the vertical tire force is difficult. Measuring the deflection of tires is often an alternative. Due to the elasticity of tires, this deflection is proportional to the vertical tire force.

For calculation of the vehicle handling (Mitschke, 1984) [13] defined a factor called RLF "Radlastfactor". When calculating this coefficient, the static vertical force of the tires was considered in addition to the dynamic vertical force of the tires. The RLF is equal to the tire's dynamic force on the tire's static force. Greater value of this factor means higher instability in the tire contact, implying worse handling. In another related study about tractor dynamics, RLF factor was used also for examining handling of tractors. The conclusion of this investigation is that the handling of tractors is acceptable if the RLF value is lower than 0.33 (Ulrich, 1983) [14]. This factor was also used by (Hoppe, 2006) [15] in order to evaluate the handling capability of a full suspension tractor.

Handling capability for the farm tractors is particularly important. Further differences are the higher body mass and the lacking chassis suspension. As a result, tractors have normally poor roll and pitch stability. In extreme situations poor handling may lead to very weak steering and braking control ability of the vehicle. On the other hand, effective agricultural processes need a higher tractor velocity. This demand leads to an increasing importance of the handling capability for agricultural tractors.

In the investigation of (Simon, 2001) [16], it was concluded that the limit of the handling performance of automobiles is characterized by the loss of the yaw stability, whereas this limitation in off-road vehicles should be characterized by the loss of the roll and pitch stability. In this investigation, the main objective was improvement of the tractors handling. It was concluded that this can be achieved via providing a better control on the vibrations of the tractor body (i.e. roll, pitch, and heave) by using an effective chassis suspension for the tractor.

II. LINEAR MODELS & REGRESSION ANALYSIS

Suppose that the result of any process is determined by a random variable, called a dependent variable (or test), depends on k independent (or explanatory) variables determined by X1, X2, ..., Xk. Assume that the y behaviour can be explained by the relationship given by

$$y = f(X1, X2, ..., Xk, \beta1, \beta2, ..., \beta k) + \varepsilon$$

Where f is a well-defined function, and β1, β2, ..., βk are parameters that characterize respectively the role and contribution of X1, X2, ..., Xk. The term ε reflects the stochastic nature of the relationship between y and X1, X2, Xk and indicates that this relationship is not strict. When ε = 0, the relation is called a mathematical model, otherwise it is a statistical model. The term "model" is widely used to represent any phenomenon within a mathematical framework.

The model or relation is called linear if it is linear in parameters and not linear if there are no linear parameters. If one of the partial derivatives of y in relation to any of β1, β2, βk is not independent variable, the equation is called a nonlinear.

When the function *f* is linear in the variable, then y = f (X1, X2, ..., Xk, β1, β2, ..., When the function *f* is linear in the variable, then y = f (X1, X2, ..., Xk, β1, β2, ...,βk) + ε is called the linear model, and when the function fn is not linear in parameters, it is said then about the non-linear model. In general, the function f is selected as

$$f(X1, X2, ..., Xk, \beta1, \beta2, ..., \beta k) = \beta1X1 + \beta2X2 + ... + \beta kXk$$

Description of the linear model Because X1, X2, ..., Xk are predetermined variables and *y* is the result, both are known. Therefore, knowledge of the model depends on the knowledge of the parameters β1, β2, ...,β k.

Static linear modelling consists essentially in the development of methods and tools for determining β1, β2, ..., β k in a linear model.

$$y = \beta1X1 + \beta2X2 + ... + \beta kXk + \varepsilon$$

Given the observations on *y* and $X_1, X_2, \ldots, X_k$,

Various statistical estimation methods can be used, for example, the maximum likelihood method, least squares principle, moments method, etc. estimate model parameters. The maximum likelihood method requires better knowledge of the distribution and method of moments, and the smallest square does not require knowledge of the *y* distribution.

Regression analysis is a tool for determining parameter values based on data *y* and X1, X2, ..., Xk,. The literal meaning of regression is "to go in the opposite direction". Before discussing and understanding the meaning of the word "reverse direction", let's see which of the following statements is correct:

1) S1: the model generates data or
2) S2: data generates the model.

Of course, S1 is correct. In general, it can be assumed that the model exists in nature, but is not known to the experimenter. When certain values are assigned to explanatory variables, the values of the output or test variable are generated respectively, depending on the form of the function f and the nature of the phenomenon. Thus, the earlier model is best generated data. Our goal is to determine the functional form of this model. Now we're coming back. We propose to first collect the data on study and explanatory variables. Then we use the statistical technique and use this data to learn the form of the function f. At the same time, the model data is first registered and then used to determine the model parameters, first registered and then used to determine the model parameters. Regression analysis is a technique for determining a statistical model using data from research and explanatory variables. .

III. RESULTS FOR REGRESSION ANALYSIS

The regression model is a statistical process that allows the researcher to estimate the relationship with the linear, most variable line. This model can also be used to determine the importance of statistics, to verify if the linear relationship seen can arise from the opportunity. In the second curriculum of statistical methods, multiplexing regression was examined with relations between multiple variables. The delayed variable regression model specifies the position of a variable to a variable, and the other changes the position of a dependent variable. The independent variable can be considered as a variation on the dependent variables, where dependencies of independent variables can be used at the moment of variation. It will be seen that the investigator is no longer in charge of a reallocation of causality, included in the Regression model. If, however, the investigator likes a reason to convert a variable into a variable, then it is possible to estimate the way in which it relates to cars in the independent dependency variable. To use the regression model, the expression for the straight line checks first. This is given in the following section. Once you have found it, you do not have a formula to determine the regression line of the observed data.

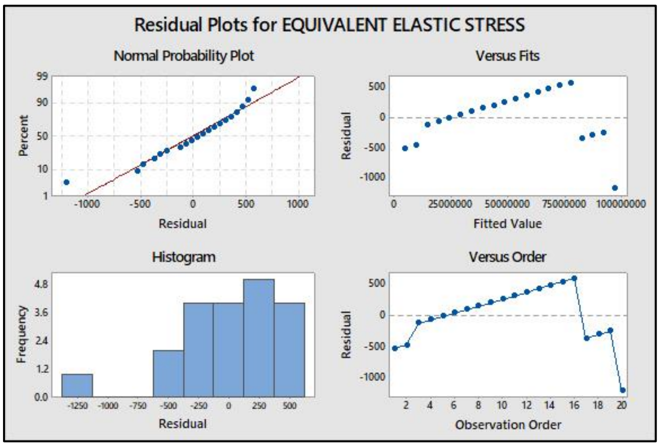

Fig. 1: Residual Plot for Equivalent Maximum Stress for Suspension Spring

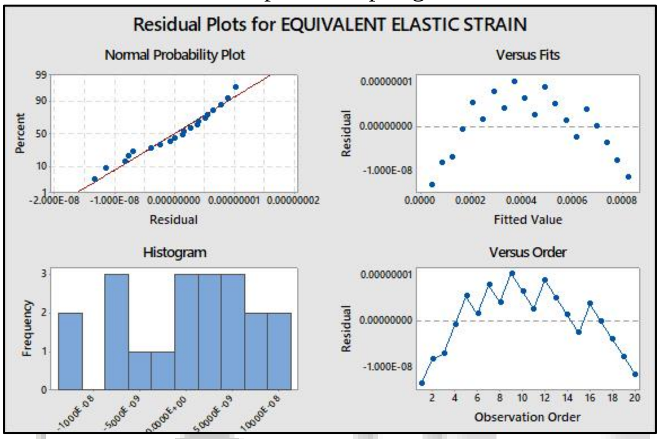

Fig. 2: Residual Plot for Equivalent Maximum Shear Strain for Suspension Spring

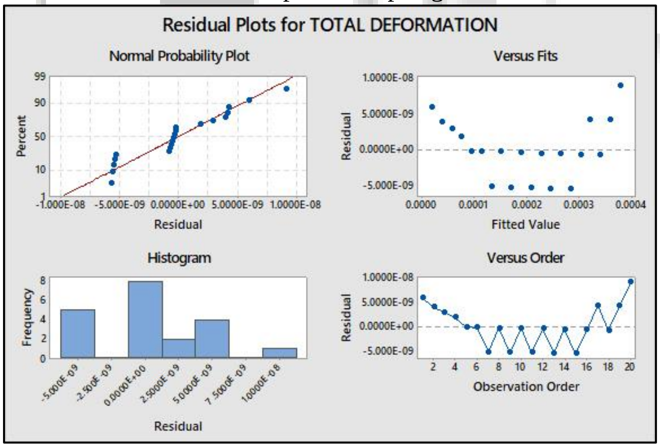

Fig. 3: Residual Plot for Maximum Total Deformation for Suspension Spring

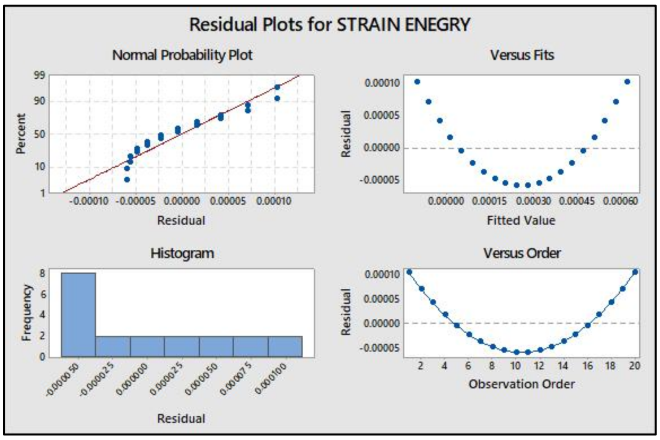

Fig. 4: Residual Plot for Strain Energy for Suspension Spring

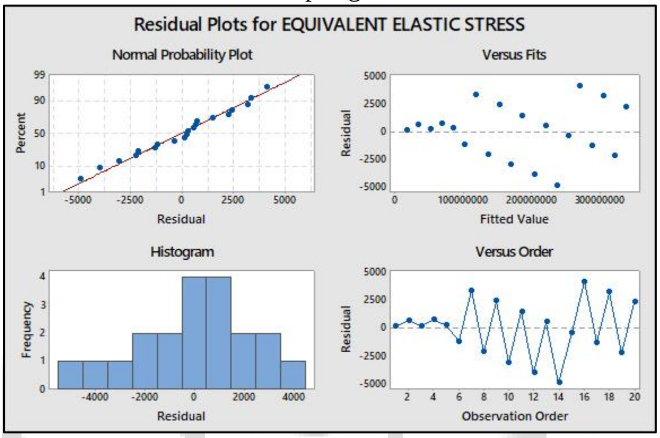

Fig. 5: Residual Plot for Maximum Equivalent Stress for Suspension Clamp

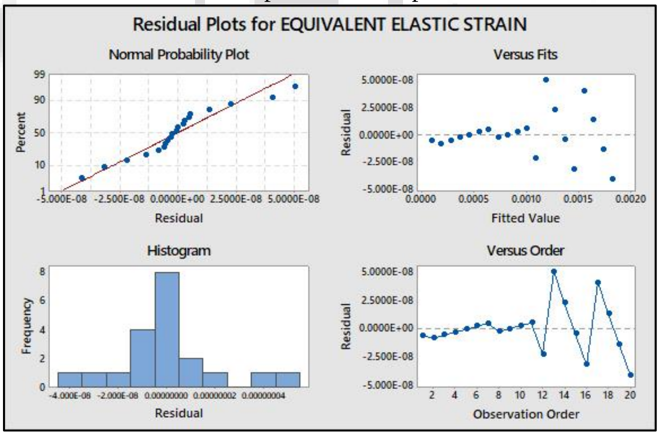

Fig. 6: Residual Plot for Maximum Equivalent Shear Strain for Suspension Clamp

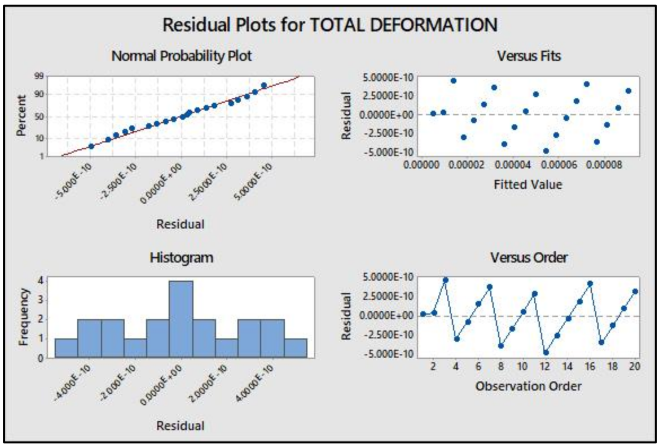

Fig. 7: Residual Plot for Maximum Total Deformation for Suspension Clamp

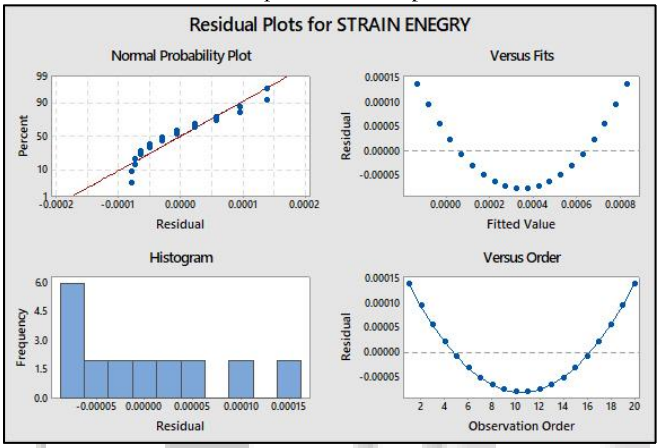

Fig. 8: Residual Plot for Strain Energy for Suspension Clamp

IV. CONCLUSION

From the above graphs, it is found that Equivalent stress, Equivalent Shear Strain, Total Deformation and Strain Energy for both Suspension Spring and Clamp is well predicted by the regression modal.

Hence, Regression Analysis Model is a good tool of Minitab to predict the Different performance characteristic of any working mechanical model.

On the basis of the current work, it is concluded that any Performance parameter can be efficiently predicted by the Regression Analysis.

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