Online available since 2014/Jun/30 at www.scientific.net
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doi:10.4028/www.scientific.net/AMR.980.219

# New Model for Knock Factors Optimization in Internal Combustion Engine (SI)

Azher Razzaq Hadi Witwit[1, 2 a], Azman Yasin[1, b], Horizon Gitano[3,c], Tarun Kumar Yadav[4,d]

[1]University Utara Malaysia(UUM), Kedah, Malaysia

[2]University of Babylon, Babylon, Iraq

[3]University Kuala Lumpur Malaysian Spanish Institute (UniKL MSI), Kulim, Kedah, Malaysia

[4]University Putra Malaysia (UPM), Kuala Lumpur, Malaysia

[a] azherwitwit@yahoo.com , [b] yazman@uum.edu.my , [c] horizonusm@yahoo.com, [d] 77.tarun@gmail.com

**Keywords:** Knock, Curve Fitting, Akaike Information Criterion (AIC), Throttle Position sensor (TPS).

**Abstract**: The main goal of this paper is to construct a new mathematical model and study the behavior of the factors affecting the problem of knocking in internal combustion engines. Curve fitting technique was used in construction of the model, and also Akaike Information Criterion (AIC) was used as a test in choosing the best model. Factors affecting the problem of knocking have been identified through the use of test engine had promised to do so. The mathematical model was built through real data under certain conditions. Three influential factors (Temp., TPS and RPM) have been taken into consideration. Curve fitting models were used in achieving the goal and then studied the effect of one of the factors in the problem of knocking was investigated. Results obtained through the application of the new model is a low level knocking with increasing temperature (Temp) at the same points in Throttle (TPS), the Revolution Per Minute (RPM), which shows the effectiveness of the new model with non-linear behavior of the factors affecting the knock.

## Introduction

Knock in gasoline engines is one of the major challenges to achieve higher performance efficiencies. To improve the control systems, the behavior of the knocking and the factors affecting this problem should be studied. It is known that the nature of the factors that influence the behavior of the knocking are non-linear, so the study of the relationships between these factors is critical. Thereby, it is difficult to build a control system on the knocking which works efficiently. One of the techniques that deal with the nature of the data with non-linear technique is a curve fitting.

## Curve Fitting

Curve Fitting is used to “connect” observed data to a mathematical model, this operation is very important in finding a rewarding relationship for any system [1]. It is noted that the behavior of the data of the factors is non-linear. For example, when you enter a set of inputs, you will notice that the output takes a set of points are distributed randomly with no specific relationship [2].

## Akaike Information Criterion (AIC)

Akaike Information Criterion (AIC) It is a measure of the relative quality of a model for a set of data providing a tool for model selection. AICc deals with trade-off among the complexity and goodness of fit of the model. It provides a relative estimation of the information lost when a model is applied to represent the process that generates the data. AIC does not present a test of a model in the case of examination of a null hypothesis, i.e. AIC may tell nothing about the model quality in an absolute sense. If all the models fit poorly, AIC will not offer any warning of that. Generally, the AIC is calculated through the following formula:

$AIC=2R-2\ln(L)$

Where:

$R$ is the number of parameters in given statistical model.

$L$ is the maximized value of the likelihood function of the estimated model.

Many researchers have used different types of appropriate curve fitting solutions in resolving different kinds of problems in many areas. One approach that deals with appropriate curve fitting is in the field of image processing (image segmentation) by [3]and others, where an effective method has been developed for the study of cervical vertebra maturation (CVM) for bone age evaluation. The researchers applied a curve fitting method based on rotating and overlapping parabolic curves to derive the final segments of the cervical vertebra. Another study by researchers [4], dealt with a programme verification problem of the positively invariant sets of a class of nonlinear loops and discussed the relation between these sets and the attractors of the loops. In this study researcher suggested a numerical method based on curve fitting determined by an algebraic polynomial of degree 5 to find a positively invariant set containing the strange attractor for the H’enon map. Researcher L. Shen conducted a number of studies related to the same issue, but with a linear behaviour [5,6,7,8,9]. Another researcher established an engine dynamic model based upon a theoretical approach and supplemented the acquired engine experimental data using a dynamometer setup. Experimental data was employed to obtain the relation between the throttle valve opening, injected fuel amount, ignition timing, air/fuel ratio, engine speed and generated torque using curve fitting techniques. Accordingly, the gathered experimental input-output relations for coexisting physical quantities were curve-fitted to acquire interpolated functions with the purpose of achieving a complete model for simulations of that particular engine [10]. In addition, some professionals set up fuel injection systems on certain motorcycle engines with the aim of investigating the influence of fuel injection pressure, fuel injection width, and fuel injection timing on engine combustion performance under different load and speed operating conditions [11,12]. In 2006 researchers Yongping, H., et al. developed a steady state power model of a fuel cell stack based on a polarization curve. On the basis of the experimental results, a parasitic system power model was developed by fitting the experimental data with a quadratic polynomial [13].

## Achievement of This Study

The aim of the current study is mainly to choosing the best model from a group of nonlinear models applied to real data for a variety of nonlinear factors that affect the accuracy in internal combustion engines. These data were obtained from test engines at the Proton company in Malaysia. The tests were applied through the execution of an applications set to find the appropriate curve fitting for the data, like (Curve Expert Professional v2.0.0).

## Experimental Aspect of the Study

The experimental aspect of the study was done through the application of the data obtained for the influential factor TPS, regarding the set of functions to get the best possible model that fits the data, as given in Fig.(1):

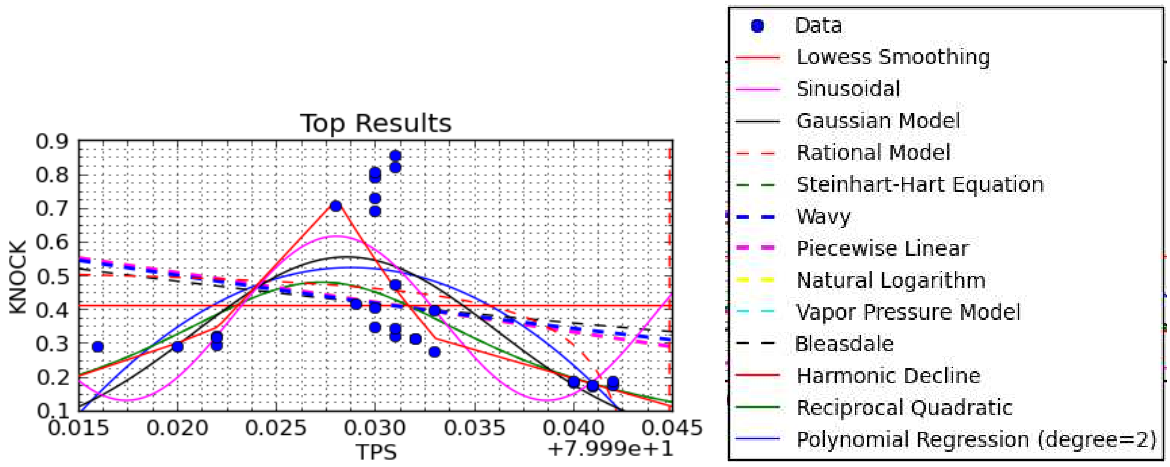


Figure (1): Curve fitting models for Tps factor.

After doing a series of the calculations on a group of models in order to assess and determine the best model of them the following results were obtained, as shown in table (1):

Table (1): Best Model for Tps factor

| Name | Kind | Family | Score | R | R^2 | Std_Err | AICC |
|---|---|---|---|---|---|---|---|
| Sinusoidal | Regression | Miscellaneous | 525 | 0.733239 | 0.537640 | 0.162446 | -99.091. |
| Gaussian Model | Regression | Miscellaneous | 489 | 0.690112 | 0.476255 | 0.169400 | -98.120. |
| Polynomial Regression (degree=2) | Regression | Linear Regressions | 461 | 0.653337 | 0.426849 | 0.177210 | -95.596. |
| Steinhart-Hart Equation | Regression | Miscellaneous | 438 | 0.619208 | 0.383419 | 0.183802 | -93.551. |
| Reciprocal Quadratic | Regression | Yield-Density Mod... | 438 | 0.619214 | 0.383426 | 0.183801 | -93.551. |
| Rational Model | Regression | Miscellaneous | 377 | 0.494487 | 0.244517 | 0.207649 | -85.342. |
| Natural Logarithm | Regression | Exponential Models | 339 | 0.262106 | 0.068700 | 0.221504 | -84.330. |
| Wavy | Regression | Custom | 337 | 0.233177 | 0.054372 | 0.223202 | -83.903. |
| Piecewise Linear | Regression | Custom | 333 | 0.262139 | 0.068717 | 0.230547 | -79.485. |
| Bleasdale | Regression | Yield-Density Mod... | 333 | 0.219354 | 0.048116 | 0.228374 | -81.392. |
| Harmonic Decline | Regression | Imported | 331 | 0.008189 | 0.000067 | 0.229521 | -82.339. |
| Vapor Pressure Model | Regression | Exponential Models | 157 | 0.000000 | 0.000000 | 0.467316 | -41.295. |

Table above shows the value (-99.0911) of the AICc for the first model (sinusoidal), as well as the value of the standard error as less as possible, and the R^2 which is the best of all. Therefore, it has been chosen as the best (model sinusoidal) which model can represent data for influential factor TPS, seen in Fig (2).

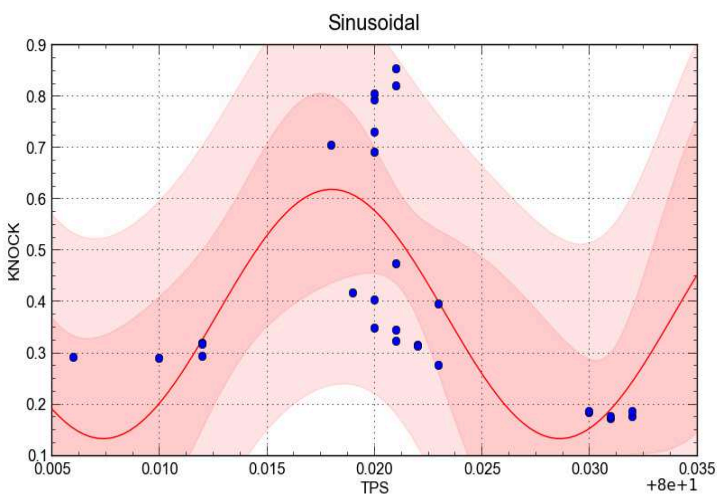


Figure (2): Sinusoidal model for Tps.

After that we can obtain the formula and its parameters as it showing below:

**Overview**

| | |
|---|---|
| Name | Sinusoidal |
| Kind | Regression |
| Family | Miscellaneous |
| Equation | y = a + b*cos(c*x + d) |
| # of Indep. Vars | 1 |
| Standard Error | 0.162446 |
| Correlation Coeff. (r) | 0.733239 |
| Coeff. of Determination (r^2) | 0.537640 |
| DOF | 24 |
| AICC | -99.091172 |

**Parameters**

| | Value | Std Err | Range (95% confidence) |
|---|---|---|---|
| a | 0.376553 | 0.031781 | 0.310959 to 0.442146 |
| b | 0.243041 | 0.088041 | 0.061334 to 0.424749 |
| c | 295.873652 | 28.390305 | 237.278942 to 354.468361 |
| d | -14005.390028 | 2271.759927 | -18694.072074 to -9316.707983 |

The same procedure was carried out on other factors alone (RPM, TEMP). In this study the partial effect of each of the factors, affecting the process of the knocking, and thus find the sum of these effects on those factors in creating the overall effect of the factors on the knocking was found. At the beginning, a better model was taken for one factor that affects knocking, and then find the first derivative of the model in order to find the partial effect of the factor after applying real data considering fixed values of other factors. The proposed model, which consists of three factors with non-linear behavior, was used for the first derivative to reduce the complexity of the model assumed.

$$knock = a + b*\cos(cTps + d), \quad dk = \left(\frac{\partial k}{\partial Tps} dTps\right)_{Rpm,Temp}, \quad \frac{\partial k}{\partial Tps} = -bc\sin(cTps + d) \tag{1}$$

Where $k$ denoted to *knock*. Also take (*Rpm*) factor:

$$knock = p + qRpm + sRpm^2, \quad dk = \left(\frac{\partial k}{\partial Rpm} dRpm\right)_{Temp,Tps}, \quad \frac{\partial k}{\partial Rpm} = q + 2sRpm \tag{2}$$

Also take (*Temp.*) factor:

$$knock = m + n*\cos(oTemp + e), \quad dk = \left(\frac{\partial k}{\partial Temp} dTemp\right)_{Rpm,Tps}, \quad \frac{\partial k}{\partial Temp} = -no\sin(oTemp + e) \tag{3}$$

So, we can get an overall model, which can be used in the analysis of the effect of factors on knocking, since the knocking depends upon the Rpm, temperature and Tps, Thus, we can have the following formula:

$k = k(Rpm, Temp, Tps)$

To get the relation among RPM, TEMP and TPS, we used partial deferential

$$dk = \left(\frac{\partial k}{\partial Rpm} dRpm\right)_{Temp,Tps} + \left(\frac{\partial k}{\partial Temp} dTemp\right)_{Rpm,Tps} + \left(\frac{\partial k}{\partial Tps} dTps\right)_{Rpm,Temp} \tag{4}$$

Substituting the value of (1),(2),(3) from above eqns in eqn (4) we get:

$$dk = (q + 2sRpm)_{Temp,Tps}\, dRpm + [-on\sin(oTemp + e)]_{Rpm,Tps}\, dTemp + [-bc\sin(cTps + d)]_{Rpm,Temp}\, dTps$$

*Knock*= -0.24304*292.873* sin(292.873*tps-14005.39002) -2.08452 + 2* 0.00117* rpm - 0.09226 * 38.29344 * sin(38.29344*temp+32.15755)

For example, if take the factor TPS, with the consideration of the fixed values of the other factors, and apply the overall in formula in many situations to investigate its effect on knocking, the following results are obtained, as the shown in fig. (3). The behavior of knock appeared in different (RPM) like 2000,4000,5000.

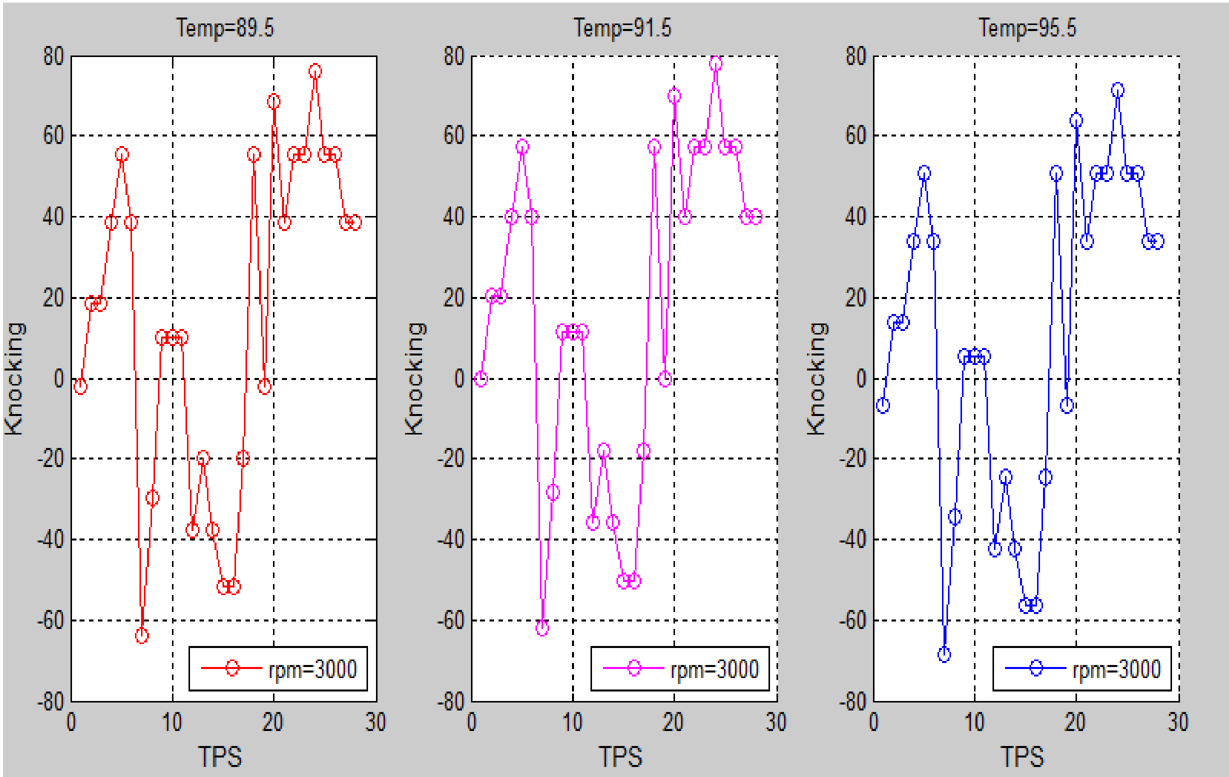


Figure (3): Effect TPS in defferent (Temp.) on knocking

## Summary

By observing the figure above (3), you will note the change in knocking when the values of TPS changes, with fixed temperature (Temp.) in the value of 89.5, and engine cycle (RPM) equals 5000, the value of the knocking will be equal 80. After increasing the (Temp) to 91.5, it is observed that the knocking is also increased, but when the (Temp) is continues rising, knock starts to decrease. Results obtained through the application of the new model is a low level knocking with increasing temperature (Temp) at the same points in Throttle (TPS), the Revolution Per Minute (RPM), which shows the effectiveness of the new model with non-linear behavior of the factors affecting the knock.

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