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Research of the process of hogging of crankshafts with a single crank neck when stamping fillets

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Abstract. The article describes the results of the research of the process of hogging of crankshafts (CS) with a single crank neck when stamping fillets and a computer program with the help of which it is possible to calculate the expected magnitude and direction of hogging of CS and also to select a combination of stamping modes at which the amount of hogging that needs to be done is minimal.

1. Introduction

Crankshafts (CS) are widely used in modern engineering. However, despite the extensive experience gained by experts in the design, manufacture and operation of CS, they are often destroyed in operation due to insufficient fatigue resistance. According to prof. V. P. Uskov, such destruction is observed in 2–8% of engines entering repair [1]. Destruction occurs mainly through the fillets. The most effective and easily feasible from the point of view of increasing the resistance to fatigue CS is the operation of hardening their fillets by surface plastic deformation (SPD): by rolling rollers, stamping, etc. However, as practice and numerous experiments show, the hardening of fillets CS SPD leads to hogging of CS [2]. Moreover, the more effective is the method from the point of view of increasing the resistance to fatigue, the more it leads to a greater distortion of the crankshaft. With the intensification of hardening modes, the fatigue resistance of the crankshaft increases, but at the same time the magnitude of its distortion increases too.

At the Department of Mechanical Engineering Technology of NovSU the main principles of the theory of warping of CS during the hardening of their SPD fillets have been developed [2]. In particular, theoretical, experimental and computer studies of the process of distortion of spatial crankshafts with six crankpins (CP), which are arranged in pairs at angles of 120° [2], and with five CP located at an angle of 72° to each other were carried out [3]. The purpose of this work is to study the process of hogging with one CP during the stamping of fillets and the development of a computer program that adequately describes this process.

2. Results of the grapho-analytical research

As the object of study a CS was chosen, its design scheme is presented in figure 1. The behavior of the "ideal" CS was studied. The cheeks of "ideal" CS are of the same thickness – 20 mm, the diameters of the main crank necks (CN) and CP are the same – 48 mm, the radii of the CN and CP fillets are equal to each other – 2.2 mm, the crank radius r = 40 mm, the distance from the left support to the section AA b = 100 mm, the distance between the supports L = 95 mm.

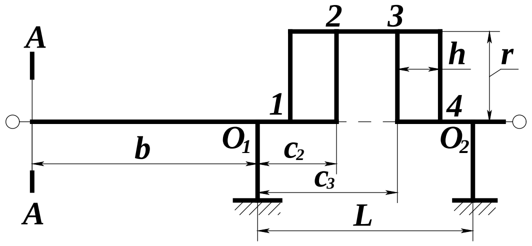

Figure 1. A scheme of an “ideal” CS.

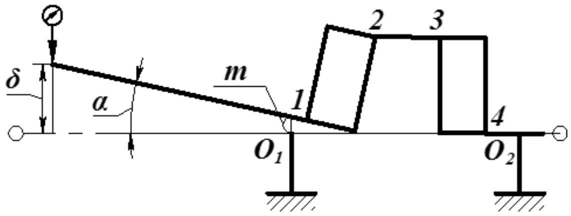

Figure 2. Hogging of a CS when stamping a fillet 2.

When stamping the fillet 2, the left cheek of the CS will bend in the area of the fillet 2 belonging to the lower generatrix CP CS (Figure 2), and CS will assume the position shown in Figure 2, which shows the full value of hogging and the corresponding angle α between the left CN and the horizontal. Since the CS has mass, it will turn around the $\boldsymbol{O_2}$ point counterclockwise until the left CN comes into contact with the $\boldsymbol{O_1}$ support (Figure 3). At the same time, the left CN forms an angle $\boldsymbol{\alpha_1}$ with the horizontal. Using the indicator, you can trace (measure) the measured hogging value $\boldsymbol{\delta_{ms}}$ in section A–A and calculate the corresponding angle $\boldsymbol{\alpha_1}$ using the formula: $\boldsymbol{tg\ \alpha_1 = \delta_{ms} / b}$. However, the total hogging value $\boldsymbol{\delta}$ and the corresponding angle $\boldsymbol{\alpha}$ remain unknown.

There are several questions:

1. What are the total hogging value $\boldsymbol{\delta}$ and the corresponding full hogging angle $\boldsymbol{\alpha}$?
2. What is the share of the measured hogging value $\boldsymbol{\delta_{ms}}$ in the total hogging value $\boldsymbol{\delta}$ (accordingly, what is the proportion of the measured angle $\boldsymbol{\alpha_1}$ in the full hogging angle $\boldsymbol{\alpha}$)?
3. Is the ratio between the measured hogging value $\boldsymbol{\delta_{ms}}$ and the total hogging value $\boldsymbol{\delta}$ (accordingly, the ratio between the measured hogging angle $\boldsymbol{\alpha_1}$ and the total angle $\boldsymbol{\alpha}$) constant, or does it change with changes in the stamping conditions?

To study these issues, as well as for the grapho-analytical study of the behavior of the “ideal” CS, T-FLEX CAD computer-aided design tools were used.

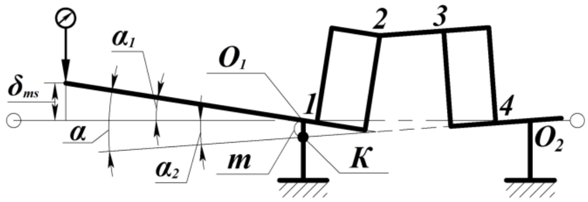

Figure 3. Full hogging angle $\boldsymbol{\alpha}$ and its elements.

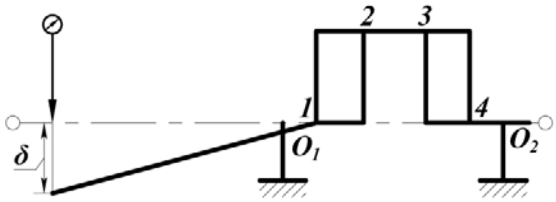

Figure 4. Hogging of CS during stamping its fillet 1.

When turning CS around point $\boldsymbol{O_2}$, the left CN will fall on support $\boldsymbol{O_1}$ by the value $\boldsymbol{m}$ (figures 2, 3). Put the value $\boldsymbol{m}$ from the point $\boldsymbol{O_1}$ down and draw a straight line through the points $\boldsymbol{O_2}$ and $\boldsymbol{K}$. This forms an angle $\boldsymbol{\alpha_2}$, the angle to which the CS turned when stamping fillet 2, it can be calculated using the formula: $\boldsymbol{tg\ \alpha_2 = m / L}$.

From Figure 3 it can be seen that the angles $\boldsymbol{\alpha_1}$ and $\boldsymbol{\alpha_2}$ together form an angle $\boldsymbol{\alpha}$. Knowing the value of the angle $\boldsymbol{\alpha}$, one can calculate the hogging value $\boldsymbol{\delta}$, using the formula: $\boldsymbol{\delta = (b + c_2)\ tg\ \alpha}$.

(The total hogging value $\boldsymbol{\delta}$ must also be known when calculating the stress state of CS elements after stamping its fillets).

When stamping fillets, 3 CS behaves similarly, i.e. the left CN rises and CS will turn around point $\boldsymbol{O_2}$ counterclockwise.

When stamping fillet 1, the situation will be opposite: the left CN will go down (figure 4), this will be prevented by the $\boldsymbol{O_1}$ support therefore, the CS will turn around point $\boldsymbol{O_2}$ clockwise (figure 4). When stamping fillet 4 CS behaves similarly. It is clear that when stamping the “ideal” CS fillets with unchanged chasing modes, the total hogging value δ and the corresponding angle α remain constant when processing any fillet.

(To calculate the total hogging value of CS, it is necessary to algebraically sum up the hogging values of the CS from stamping of all the fillets).

Thus, to find the total hogging value δ from the stamping of any fillet (for example, fillet 2), you must do the following:

1. Process the fillet 2 and set the value of δ_{ms}.
2. Calculate the angle α_1 using the formula: $tg\ \alpha_1 = \delta_{ms} / b$.
3. Calculate the angle α_2 using the formula: $tg\ \alpha_2 = m / L$.
4. Determine the angle α, corresponding to the total hogging value δ, as the sum: $\alpha = \alpha_1 + \alpha_2$.
5. Determine the total hogging value δ by the formula: $\delta = (b + c_2)\ tg\ \alpha$.

However, it is impossible to measure the value m directly during the operation of stamping fillet 2 or after it. It is possible to determine the value m, knowing the value δ_{ms}, using the computer-aided design system T-FLEX CAD, but this requires time-consuming geometric constructions in each particular case, which increases the time and labor-intensiveness of work. The situation would be greatly simplified if the fraction of the angle α_1 in the angle α had a constant value under any circumstances. Then, using the value of δ_{ms}, one could calculate the angle α_1, and from its value calculate the angle α as $\alpha = f(\alpha_1)$. Then, from the angle α, determine the total hogging δ. These actions can be carried out without the involvement of T-FLEX CAD. Therefore, the problem of conducting a grapho-analytical study of the behavior of an "ideal" CS under various conditions arises.

With an increase in impact energy, both the total magnitude of hogging δ and its measured value δ_{ms} increase. (The total angle α and the measured angle α_1 increase accordingly). In the work [2], the formula (1) for the calculation of the hogging value when stamping fillets is given:

$$\delta = K\frac{HB^{0.75}(1540-HB)(1-\nu)}{E}\cdot\frac{r}{h^2}\cdot\frac{c}{2}\cdot\sqrt[4]{E_Y D_1}\Psi, \tag{1}$$

where K is a coefficient determined experimentally;

HB is the Brinell hardness;

ν is the Poisson's ratio;

E is the modulus of elasticity of the I-kind, MPa;

r is the radius of the crank CS, mm;

h is the thickness of the CS cheek, mm;

c is distance from the left support to the processed fillet;

E_Y is the impact energy of the peen strike, J;

D_1 is the diameter of spherical head of a peen, mm;

Ψ is the coefficient taking into account the incomplete processing of a SPD cheek.

The effect of increasing the total angle α on the measured angle α_1 is shown in table 1, the results of which are used to plot the graph in figure 5. From these data it follows that with an increase in the angle α from 0.1° to 30°, the fraction of the angle α_1 increases from 63.38% to 73.02%. accordingly, with δ increasing from 0.24 mm to 71.73 mm, the share of δ_{ms} increases from 46.99% to 56.06%.

Table 1. The influence of the total angle α on the measured angle α_1, the effect of the total warping δ on the measured hogging value δ_{ms}.

α	0.1°	0.2°	0.4°	0.6°	0.8°	1°	10°	20°	30°
α_1, % from α	63.38	63.42	63.5	63.57	63.64	63.72	66.84	70.03	73.02
δ, mm	0.24	0.47	0.94	1.41	1.88	2.35	23.18	46.56	71.73
δ_{ms}, mm	0.11	0.22	0.44	0.67	0.89	1.11	11.72	24.93	40.21
δ_{ms}, % from δ	46.99	47.01	47.08	47.15	47.25	47.31	50.55	53.54	56.06

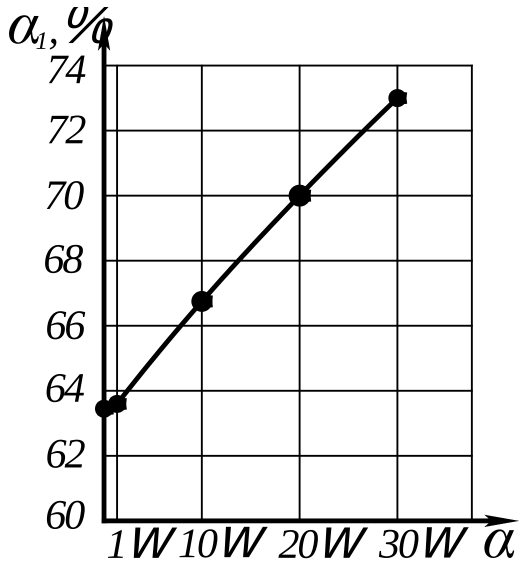

Figure 5. Influence of the full angle $\boldsymbol{\alpha}$ on the measured angle value $\boldsymbol{\alpha_1}$.

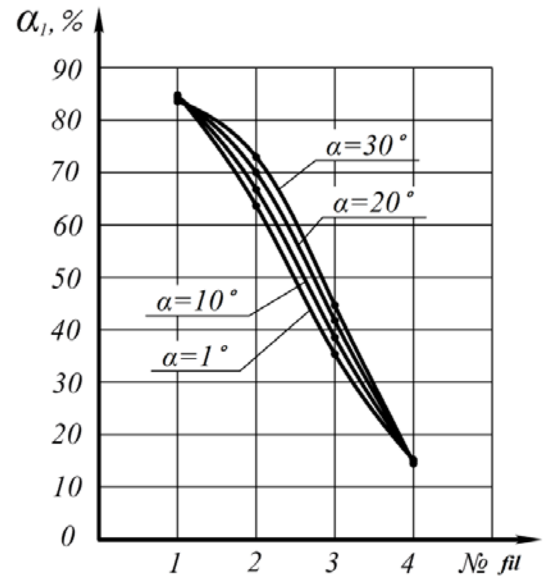

Figure 6. The effect of the distance $\boldsymbol{C_i}$ on the proportion of the angle $\boldsymbol{\alpha_1}$ in the angle $\boldsymbol{\alpha}$.

Figure 6 shows the effect of the distance $\boldsymbol{C_i}$ from the left support $\boldsymbol{O_1}$ to the processed fillet on the fraction of the angle $\boldsymbol{\alpha_1}$ in the angle $\boldsymbol{\alpha}$. As can be seen from Figure 6, with an increase in $\boldsymbol{C_i}$, it decreases sharply. Thus, the proportion of the magnitude of the measured warpage $\boldsymbol{\delta_{ms}}$ in the total hogging value $\boldsymbol{\delta}$ is not constant and depends on various factors. Therefore, the total hogging value $\boldsymbol{\delta}$ by the hogging value $\boldsymbol{\delta_{ms}}$ in each specific case should be determined individually. However, according to numerous experiments and practices, it is known that the magnitude of $\boldsymbol{\delta_{ms}}$ usually does not exceed several tenths mm (sometimes more than 1 mm), i.e. the value of $\boldsymbol{\alpha_1}$ does not exceed one degree (table 1). Within these limits, the proportion of $\boldsymbol{\alpha_1}$ in $\boldsymbol{\alpha}$ ranges from 63.38% to 63.72% (only within 0.34%), i.e. practically it can be considered constant, equal to 63.5% and used for calculations.

The coefficient $\boldsymbol{K}$ in the above stated formula according to the results of real experiments takes different values with a relatively small scattering. However, it remains unclear whether this is natural or a consequence of experimental error. A grapho-analytical study of the “ideal” CS stamping process showed that in this case the coefficient K is a constant value when stamping all four of the fillets.

Thus, the following conclusions were formulated:

1. When hogging (SPD) CS fillets and subsequent measurement of the hogging value of the CS, not the total hogging value $\boldsymbol{\delta}$ is traced, but its measured part $\boldsymbol{\delta_{ms}}$ (accordingly, not the full angle $\boldsymbol{\alpha}$, but its part $\boldsymbol{\alpha_1}$).
2. The share of the measured hogging value $\boldsymbol{\delta_{ms}}$ in the total hogging value $\boldsymbol{\delta}$ is not constant, but it varies depending on $\boldsymbol{\delta}$, the distance $\boldsymbol{C_i}$ and other factors.
3. The proportion of the measured value of the angle $\boldsymbol{\alpha_1}$ in the total value of the angle $\boldsymbol{\alpha}$ is also not constant, but it varies depending on the size $\boldsymbol{\delta}$ of the distance $\boldsymbol{C_i}$ and other factors.
4. In connection with the foregoing, in each particular case, to obtain accurate hogging values $\boldsymbol{\delta}$ and the total hogging angle $\boldsymbol{\alpha}$ corresponding to it, it is necessary to use T-FLEX CAD computer-aided design system.
5. Practically, with small values of $\boldsymbol{\delta}$ and $\boldsymbol{\alpha}$, the fraction of the measured hogging value $\boldsymbol{\delta_{ms}}$ in the total hogging value $\boldsymbol{\delta}$ varies insignificantly (tenths of a percent) and can be taken as a constant which equals to 63.5% and is used for approximate calculations.
6. The value of the coefficient $\boldsymbol{K}$ in the formula for calculating the hogging value when stamping an ideal shaft is constant.

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3. The results of grapho-analytical research

The experiments were carried out with CS having the following proportions: CP diameter is 47.2 mm, diameters of the main crank necks (CN) are equal to 50.5 mm, the crank radius r = 40.15 mm. CS cheeks have thickness of 20.5 mm on the left and 19 mm. The radius of the CN fillets is 2.5 mm, the radius of the CP fillets is 2 mm. Distance between supports L = 95.5 mm. The distance from the left support to the section A–A b = 100 mm. Material – steel 45.

The experiments were carried out with sequential stamping of fillets. The fillets were processed manually with a spherical head peen (sphere diameter is 4 mm) and a hammer in the sequence 1 – 2 – 3 – 4. The value and direction of the beating vector of the CS were measured in section A–A with the help of an indicator after each fillet was processed (Figure 1). The value and direction of the hogging vector of the CS from the processing of each fillet was calculated as the difference of the beating vectors after and before the processing of this fillet. The results of the experiments are shown in table 2 and in the graph of figure 8.

4. Description of the program

On the basis of theoretical concepts [2] and taking into account the results of grapho-analytical and experimental studies of the process of hogging CS with one CP when stamping fillets, a C# (C Sharp) program was developed using the Microsoft VisualC # 2017 Express programming environment. A block diagram of the algorithm for calculating the hogging value of the CS for stamping of fillets is shown in figure 7.

Block 1 is responsible for entering all the data required for the calculation, such as the mechanical characteristics of the material, the geometric parameters of the CS, the modes of stamping, etc.

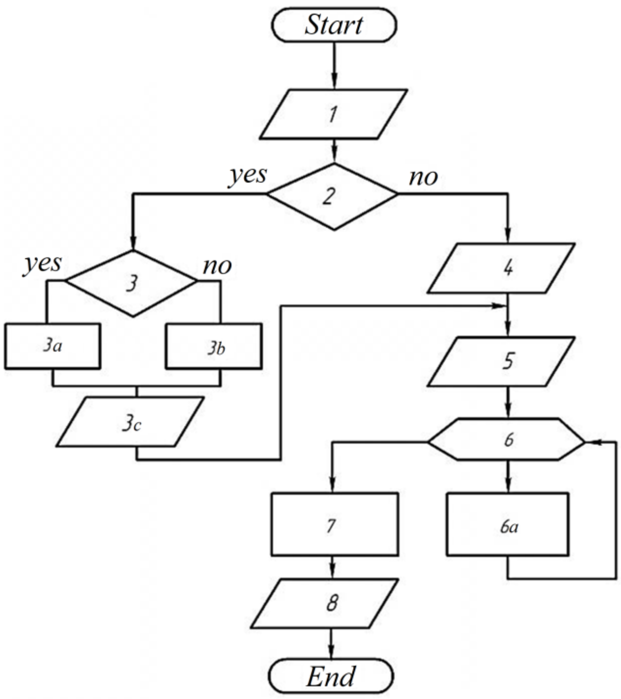

Figure 7**.** Block diagram of the program.

In Block 2, there is a choice of how to set the values of the coefficient $\boldsymbol{\Psi}$: automatic calculation or manual input.

In Block 3, the choosing of the formula for calculating the coefficient $\boldsymbol{\Psi}$ from the conditions of the relative position and sizes of CN and CP occurs. In Blocks 3a, 3b the coefficient $\boldsymbol{\Psi}$ is calculated using the selected formula, and then the calculated values are output in Block 3c.

In Block 4 the manual input of the coefficient $\boldsymbol{\Psi}$ is performed if the automatic calculation is not selected.

In Block 5, one must select the numbers of the fillets being hardened.

In Block 6, a cycle is organized to calculate hogging value for the fillets being hardened. In Block 6a, the calculation of the CS hogging value of KV when stamping a single fillet is carried out. The calculation is made according to the above stated formula [2], presented in the working window of the program.

In Block 7, the calculation of the CS total hogging value and the total beating of the CS takes place.

Block 8 is responsible for outputting the results: CS hogging and beating values after processing of fillet by stamping, CS total hogging values, CS total beating values.

In order for the program to calculate the hogging values, beating values from the hardening of single fillets, their total values, as well as to display the obtained values, one must click the “Calculate” button.

As a result, in the “Obtained Results” block, the CS hogging values are displayed after processing each single fillet. In the lower part of this block, the total CS hogging value is displayed. Total hogging value is obtained by vector summing the hogging values from those fillets numbers of which are marked with a check mark.

In the working window of the described program, the characteristics of the CS, as well as the modes of hand-stamping, were entered. The graphs of the experimental and calculated (theoretical) CS hogging values depending on the distance from the fillets to the supports, i.e. from the fillet number, are given in table 2 and figure 8. The discrepancy between experimental and theoretical points averages 10.7%. The result can be considered satisfactory, given that the stamping of the fillets was done manually. In case of manual stamping, it is almost impossible to maintain the mode unchanged (impact energy, step of plastic prints) when processing various fillets. Consequently, the developed program describes the process of CS hogging satisfactorily.

The total amount of CS hogging in section A–A after stamping of all four fillets in the experiment was (–27.5) µm. If this value exceeds the tolerance for the CS beating in section A–A, then it is necessary to adjust the stamping modes. Using the described program, the following combination of stamping modes was selected: fillet 1 – striking energy of the peen E Y = 20 J; fillet 2 – E Y = 22 J; fillet 3 – E Y = 22 J; fillet 4 – E Y = 22 J. With this combination, the CS total hogging value $\boldsymbol{\delta_{sum}}$ was (–1) µm, which is acceptable.

5. Comparison of data obtained by the grapho-analytical method as a result of the experiment and calculated by the program

Comparison of the data obtained by the grapho-analytical method, obtained as a result of the experiment and calculated according to the program, is given in table 2. The results of field experiments were used as reference CS hogging values.

Table 2. Comparison of the data acquired.

№ gal.	Experimental hogging values, µm	Grapho-analytical values of hogging, µm	The error of the experimental values,%	Calculated hogging values, µm	The error of the experimental values,%
1	–190	–180.6	5	–171.2	9,9
2	+135	+135	0	+122.7	9.1
3	+72.5	+74.8	3.2	+79.1	9.1
4	–45	–32.3	28.2	–35.7	20.7

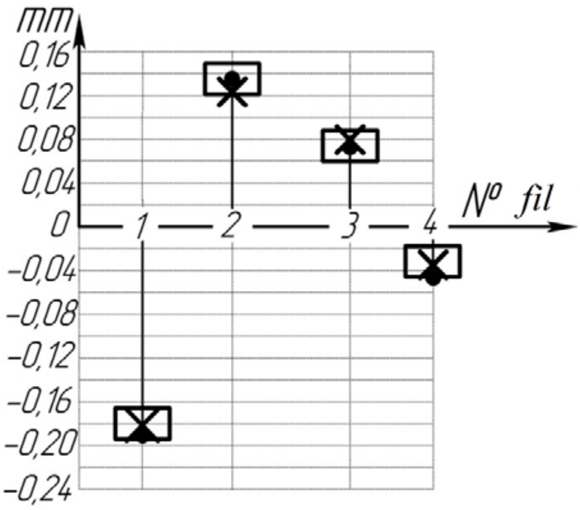

Figure 8. CS hogging graph: "□" – values obtained by the grapho-analytical method; "•" are the values obtained experimentally; "X" are the calculated values.

Thus, with the help of the developed computer program the following is possible to do:

a) at the stage of the design of the strengthening the fillets of CS by stamping operation, to calculate the expected value and direction of hogging, as well as to select such a combination of modes of hardened fillets, at which the total hogging value will be minimal;

b) to make a computer study of the influence of various factors on the hogging value of a CS with one crank neck with any combination of the sizes of their structural elements and from any metal, which as a matter of principle cannot be studied experimentally.

References

[1] Uskov V P 1998 *Spravochnik po Remontu Bazovykh Detalei Dvigatelei* [Basic Engine Repair Parts Handbook] (Briansk: Klincovskaya Gorodskaya tipografiya) p 589

[2] Zajdes S A and Emelyanov V N 2017 *Vliyanie Poverhnostnogo Plasticheskogo Deformirovaniya na Kachestvo Valov* [Influence of Surface Plastic Deformation on Shaft Quality] (Irkutsk: IRNITU) p 380

[3] Emelyanov V 2014 Research on hogging process of crankshafts with five rod journals because of fillets stamping *Journal of Engineering And Technology Research* **2 (2)** 65–69