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Machining variables optimization of turning operation for a stepped sample by using MATLAB technique

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Abstract -*In the metal cutting operation, the determination of the optimum machining variables (depth of cut, feed and cutting speed) for stepped parts is still one of the most important and difficult problem facing the production engineer. The determination of the optimum machining variables is based on economic and technological consideration. The economics of machining operation are affected by numerous variables such as cutting tool material, type of machining tool and different machining condition. In order to reduce the manufacturing costs, higher production rates should be obtained. However, the increase of the producing rate is governed by several technical restrictions, such as cutting tool life, permissible stresses of spindle, tool, speed gear box and feed mechanism, deflection of tool and machine-tool-work piece-fixture (MTWF) system, power of the machine tool and quality of surface generated. The aim of present investigation is the determination the optimum machining variables for a steeped part taking into account the objective functions and technological constraints encountered in machining operation. Also, to present the proper technique which must be carried out to achieve the desired shape of the part. the required data to solve practically this problem such as constants of cutting forces equations, overall efficiency, deflection of (MTWF) system wear obtained experimentally. The results obtained are reasonable and show a great save in production time and manufacturing costs.*

***Key Words*: *metal cutting operation; depth of cut; feed and cutting speed; optimization; strains*.**

1. INTRODUCTION

The turning processes are the metal removal from the outer diameter of a rotating cylindrical work piece. It is used to decrease the work piece diameter, generally to a specified dimension with a smooth finish on the metal [1]. In spite of the resent development of machine tools and cutting tool materials, considerably low production rates and consequently, relatively high machining cost are still remarkable feature in most machining shops. This is mainly due to the inconvenient choice of the machining variables (depth of cut, feed and cutting speed), which is usually based on mere experience and empirical rules [2]- [4]. The reduction of the machining costs can be attained by reducing both idle time and machining time. Idle time is considerably reduced by the increases of the degree of automation in machine tools, especially in case of Numerical control (N.C) machines, while a significant reduction in machining time can be attained by increasing the metal removal rate. However, this is limited by the technical restrictions encountered during machining, and dictated by the machine tool, the cutting tools and the work piece [5]. These restrictions are based upon the characteristics of the machine tool and its accuracy, the material of the cutting tool and its size and geometry, the material of the work piece to be machined, the quality of the surface generated, the type of the machining operation. Therefore, it is required to determine the best values for the machining variables taking into consideration both technical and economical point of views, to determine those values which lead to either minimum machining cost or maximum production rate and at the same time fulfill the encountered restrictions. Most of the previous metal cutting optimization studies were carried out on turning a cylindrical part with constant diameter and for single path [6]. The variables affecting the economics of a machining operation are numerous. As these variables are readily accessible on the machine tool, their selection has traditionally been considered as a part of the machine operator's duties However, the economical selection of the machining variables involves technical and cost data is not readily available to the operator, so that an optimum selection can seldom be achieved by this approach .Taylor [7] stressed this point some years ago and suggested that an optimum can only be approached if the selection is made by playing engineering with access to all relevant information. Gilbert and Brown [8] stated that a full optimization, taking in to account the interaction of all processes required to machine the part and the different values of operation at different production rates, and possible variation in anticipated sales, is seldom attempted. A procedure that is often adopted is to select conditions at each operation to give a sub-optimization. These conditions are then modified if necessary, after reviewing the process interaction by inspection of the whole production system. EL-Hakim [9] treated the optimization problem by two techniques, linear programming technique and technological logic algorithm technique to determine the optimum machining variables in turning operation for a single path and cylindrical part with constant diameter taking into account technological and economic constraints such as minimum cost as objective function, maximum power of machine tool, cutting temperature, tool chatter. The turning process is a useful machining and a versatile operation. It is the most significant processes are widely used in the manufacturing industries as a result of its capability of producing complex geometric surfaces with surface finish and reasonable accuracy [10]. EN-24 steel is one of the hard to cut metals as a result of them peculiar properties such as tendency to strain- harden and low specific heat. This gives increase to certain problems in its machining like poor surface finish, large cutting forces, built-up-edge formation and high cutting-tool temperatures [11,12]. AISI 1030 steel carried out work material and Tin-plated cutting tool used for the turning process. L9 orthogonal array used to studies the turning process characterization [13], [14]. Cemented carbide plating tool used to cut Steel of the EN 24 alloy in turning procedure. Then optimum surface roughness value and MRR predicted for produce the large variation of products in lesser time [15].

2. Review of Previous Published Studies:

Gilbert and Brown [16] stated that a full optimization, taking in to account the interaction of all processes required machining the part and the different values of operation at different production rates, and possible variation in anticipated sales, is seldom attempted.

EL-Hakim [17] treated the optimization problem by two techniques, linear programming technique and technological logic algorithm technique to determine the optimum machining variables in turning operation for a single path and cylindrical part with constant diameter taking into account technological and economic constraints such as minimum cost as objective function, maximum power of machine tool, cutting temperature, tool chatter.

HaKKi and Others [18] applied the geometric programming for determining the feed and the cutting speed of single pass turning operation. They considered the unit producing cost as the optimization criterion ,and minimum and maximum spindle speeds and feeds ,available cutting power ,allowable tool life, tolerance on the work piece diameter ,surface quality as constraints .They did not consider the cutting temperature ,tool stresses and shatter resistance as technical constraints in their work and the neglected the value of depth of cut as a cutting variable.

El-Kadeem and El-Dardiry [19] treated mathematically the problem of determining the optimal machining condition in turning operating (roughing and finishing). The constants taken into consideration were maximum power of machine tool, maximum allowable cutting force and feed limit for the desired component surface finish. The study was on single and multi-pass machining but for a constant diameter component, and they assumed that the depth of cut for each pass is constant.

Abu El Naga and El-Midany [20] treated the problem of determining the optimum cutting condition for stepped part turning. A weighted objective function which is a combination of production cost and production rate was used at different weighting factors according to the production requirements under consideration. They constructed a computer program to solve this problem for roughing and finishing operation. They assumed that a computer optimization should be carried out to find the optimal set of condition which can be used for all steps without interrupting the machine setting to reduce the producing cost and to increase the production rat and profit. They did not take into consideration the constraints encountered during machining such as cutting temperature, tool stresses, chatter resistance and stability of system as well as surface quality and deflection of (M.T.W.F.) system.

Moussa [21] treated the problem of optimum machining conditions for single pass with constant diameter component in case of production line method and free production. He constructed a computer program to determine the optimum machining variables for minimum cost and for maximum production rate.

Hitomi [22] presented an analytical approach for the determination of optimal or near-optimal cutting speeds at various stages of a multistage machining system. This approach does not consider any constraints and becomes in-effective if one is required to find two or more machining conditions such as depth of cut, feed and cutting speed at each stage of the system.

Rao and Hati [23] formulated the problem of determining the optimum cutting conditions for a job requiring multiple machining operations as a constrained mathematical programming problem. The machining of a gear blank was considered and the major operations were turning, drilling and milling. The objective functions were minimum production cost, maximum production rate and maximum profit. They solved the problem for two different cases for the first objective function (minimum production cost). In the first case, no restrictions were placed on the time taken by the individual operations and objective function was taken as the minimization of the cost of turning, drilling and milling. In the second case, some constraints were introduced on the relative time taken for the different operations and the idle costs were included along with the three machining costs in the objective function. The sequence of operations was taken as turning, drilling and milling. The problem has been solved by using nonlinear programming technique.

BROWN [24] showed that for a multi pass turning operation with no constraints, except maximum feed, single pass operation would be cheaper than double pass operation, and that the optimum cutting conditions for this restrictive case can be determined analytically. He also studied the multi pass turning operation under certain generalized constraints. Ermer and Pradhan [25] showed by example that a double pass operation may be more economical than a single pass operation when such practical constraints as surface finish and horsepower severely restrict the single pass cutting conditions. They did not consider more than one depth of cut combination for the roughing and finishing passes.

Ermer and Kromodihardjo [26] showed by several examples that the multi pass operation is more economical than the single pass operation when it is severely restricted by practical machining constraints. They applied the geometrical programming combined with linear programming and consideration only the surface roughness and the horsepower as constraints.

Abo khashaba and El-Midany [27] treated the optimum sequence of operation problem in turning. They compared between two methods to produce a stepped part, but they considered the same values for cutting variables (depth, feed, velocity) in the two methods and consequently the same machining time. The difference between the two methods was due to the number of operation for each method and consequently the handling and loading time. In practice, each stage has a certain cutting variables (d, f and v) according to the investigations in this field, it is clear that the problem of the determination of optimum machining variables for stepped part turning is still unsolved. The aim of the present investigation is to determine the optimum machining variables for stepped part turning taking into consideration the economic and technological constraints encountered in machining operation and the best method to produce the stepped part to solve the manufacturing cost and production time.

Optimization of the machining variables

A technological logic algorithm for the optimization of the machining variables was used according to the following steps:

Determination of the Initial Values of the Machining Variables

1. The depth of cut (d)

According to the optimization aim, the depth of cut must be selected as large as possible to reduce the number of passes and consequently to reduce the machining time and the manufacturing cost. The initial value will be the largest possible depth of cut which is to be determined from the machining allowance in a single pass as follows:

$A_{max} = (d_w - d_f) / 2 \quad d = A_{max}$

2. The feed (f)

After the determination of the depth of cut (d), the value of the feed (f) has to be determined from the constraints which involve both of the two variables. Each constraint gives a certain value of feed (f). The initial value of feed (f) will be the largest permissible feed obtained from the constraints using the exchange method, the algorithm for finding (fmax) will be as follows:

(a) The permissible values of the feed (fi) are determined from the different constraints, were (i) is the constraint order.

(b) The first feed (f1) is stored as an initial value.

(c) The second feed (f2) is compared with the stored value (f1). If the stored value is smaller than the second feed, delete the second feed otherwise the second feed will be the stored value.

(d) All other feeds given by the different constraints are compared with the stored value until a value is obtained which satisfies all constraints and hence will be the maximum permissible value. This can be expressed as follows:

$$f_{max} = \mathrm{Min}\,(f_i) \quad f = f_{max} \quad (i = 1,2,3, \dots ,8)$$

It will be necessary to select the feed value (f) from the available values according to the capacity of the feed gear box

Where,

$$f_L \le f \le f_u$$

(f_L, f_u) = the lower and upper feed in feed gear box respectively

3. The optimum tool life

The initial value of the tool life will be the optimum tool life; which is calculated according to the objective of the process. For minimum manufacturing cost the optimum tool life is given by:

$$T_{opc} = C2/C1\ (1-m/m)$$

- For maximum production rate the optimum tool life is given by:

$$T_{opr} = T_{ct}\ (1-m/m)$$

4. The cutting speed (v)

Using the extended Taylor relationship which is given by equation (3.2) as follows:

$$v_{op} = (C_v/T^m_{op}.\ f^p.\ d^q)$$

by substituting for (Topt), the corresponding optimum speed is obtained:

$$v = v_{op}$$

The workpiece revolution per minute according to the following equation:

$$N_w = (1000.V_{op})/(\pi.d_m)$$

It will be necessary to select the speed value (Nw) from the available values according to the capacity of the speed gear box (Nex).

Calculate the exact cutting speed according to (Nex)

$$V_{ex} = (\pi.d_m.N_{ex})/1000$$

The initial values of the machining variables, with which the program will start, are therefore,

$d = A_{max} \quad f = f_{max} \quad v = v_{ex}$

Analysis Software MATLAB

MATLAB software is a statistics package used for analysis of experimental data. The aims of experimentation are to find machining variables optimization of Turning operation for a stepped sample

3. Experimental work

Two sets of experimental were conducted on the work piece material. The first set was carried out to study the effect of the radial force component (F_y) on the relative deflection between the tool and the work piece ($\delta\omega$) under static conditions. The second set was carried out by using high speed steel tools to study the effect of the machining variables on the cutting force components and the machine tool overall efficiency under dynamic conditions. All the experiments were conducted, under dry cutting condition. The rang of cutting speeds used was from 8 to 50 m/min., while that for feeds was from 0.10 to 0.31 mm/rev. The depth of cut also varied from 1.0 to 2.5 mm.

3.1 Experimental technique

To study the effect of the depth of cut on the cutting force components and the overall efficiency, the experiments were carried out at constant feed (0.10 mm/rev) at different cutting speeds according the following procedures:

-Set up the machine and the instruments.

-Fix the work piece between chuck and tail stock, and the tool in the dynamometer.

-Adjusting the zero reading of the force dynamometer and the power instrument.

-Adjusting the considered cutting variables (d, f, and v).

-Records the values of the cutting force components and the consumed power (no load power + cutting power) during cutting operation after the indicators of the two instruments in stable reading.

-The above steps were repeated for the different values of cut.

Similarly, to study the effect of the feed on the cutting force components and the machine tool overall efficiency, the previous procedures follow at different values of feeds at constant depth of cut (1.0mm) at different cutting speeds.

From the above results, we can obtain the effect of the cutting speed on the cutting force components and the overall efficiency at constant depth of cut at different feeds, and at constant feed at different depth of cuts.

The machine tool overall efficiency was determined according to the following procedures:

-The required power consumed (p_r) at cutting process was measured in (watts) by using the power measuring instruments.

-The cutting power (p_c) was calculated by using equation

-The machine tool overall efficiency was then determined as follows:

The effect of the rake angle on the cutting force components and the overall efficiency can be studied at constant machining variables (d, f, and v) according to the procedures of the effect of both depth of cut and feed on these quantities.

4. Results and Discussions

4.1 The results of cutting forces

The cutting forces are affected by the machining variables in different ways.

4.1.1 Influence of the depth of cut (d)

The effect of the depth of cut (d) on the cutting force components (F_Z , F_X and F_Y) is shown in Fig. 1 to Fig. 5 at different cutting speeds and at constant feed of 0.10 (mm/rev)

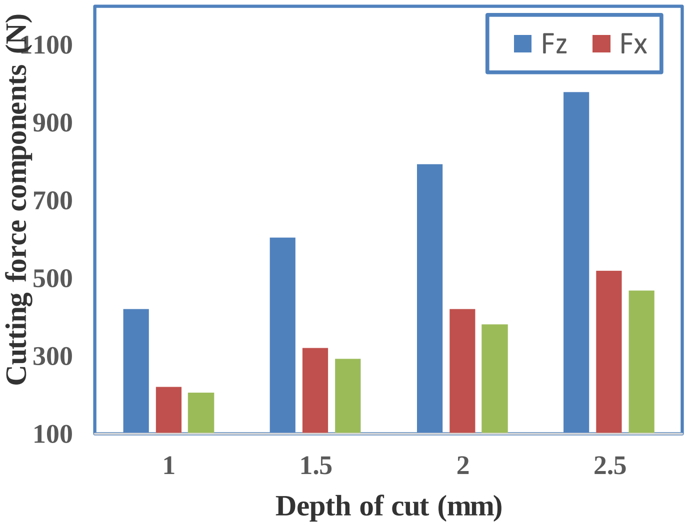

Fig.1. Effect of the depth of cut (d) on the cutting force components at V=10m/min and f=0.10 mm/rev.

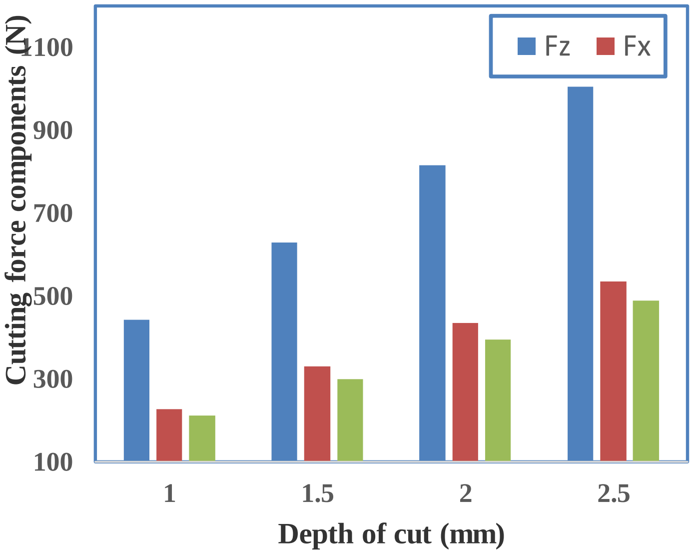

Fig. 2. Effect of the depth of cut (d) on the cutting force components at V=14 m/min and f=0.10 mm/rev.

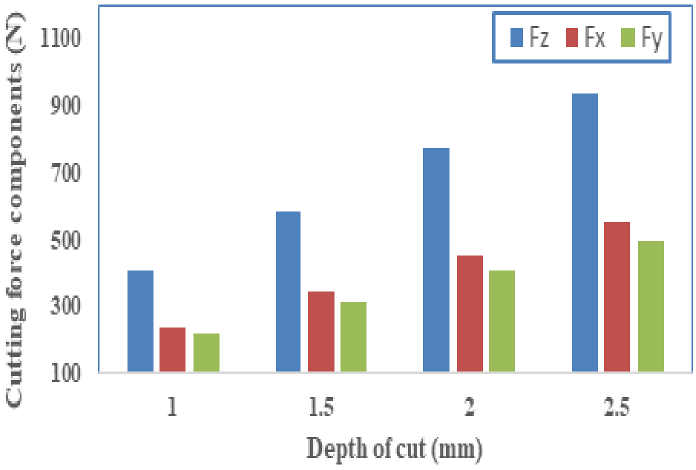

Fig.3. Effect of the depth of cut (d) on the cutting force components at V=20 m/min and f=0.10 mm/rev.

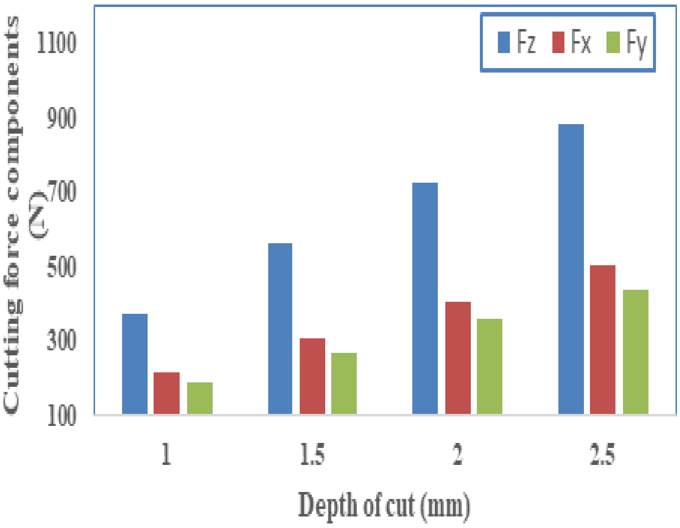

Fig.4. Effect of the depth of cut (d) on the cutting force components at V=29 m/min and f=0.10 mm/rev.

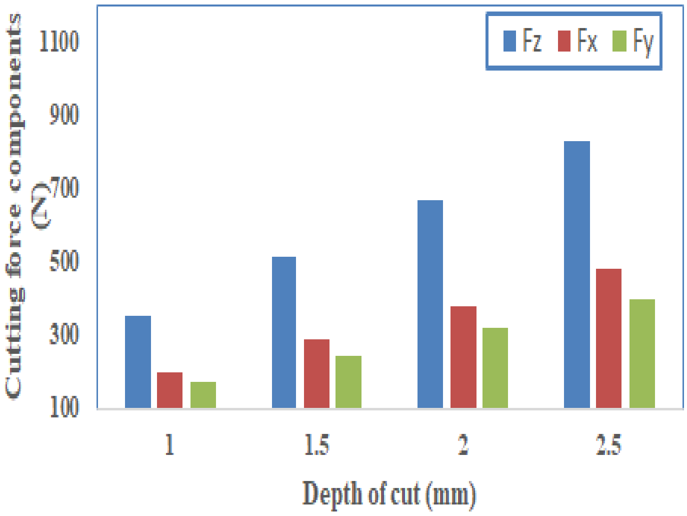

Fig.5. Effect of the depth of cut (d) on the cutting force components at V=40 m/min and f=0.10 mm/rev.

It is clear that the cutting force components increase with the increase of the depth of cut due to the proportional increase in the width of cut (b) which leads to the increase of the cutting forces. The relation between the cutting force components and the depth of cut could be approximated to a linear relationship.

4.1.2 Influence of the feed (f)

The effect of the feed (f) on the cutting force components is shown in Figs.6 to Fig.10 at different cutting speeds and at a constant depth of cut of 1.0 mm.

With the increase of the feed, the unreformed chip thickness (t_1) increases, and this led to the increase of the cutting forces.

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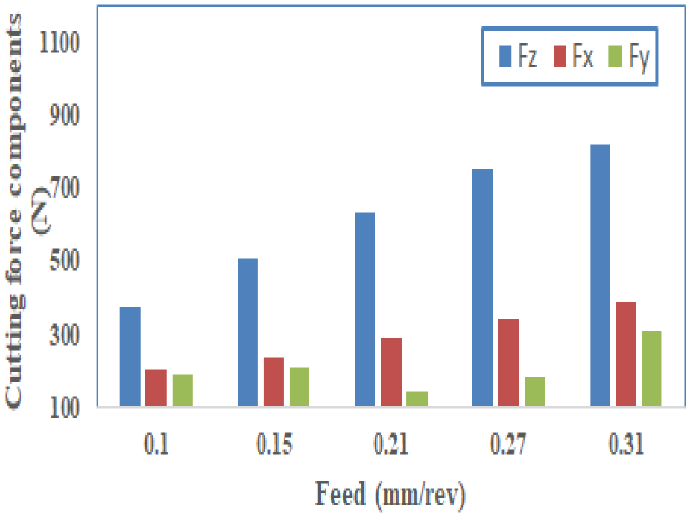


Fig.6. Effect of the feed (f) on the cutting force components at V=8.4 m/min and d=1 mm.

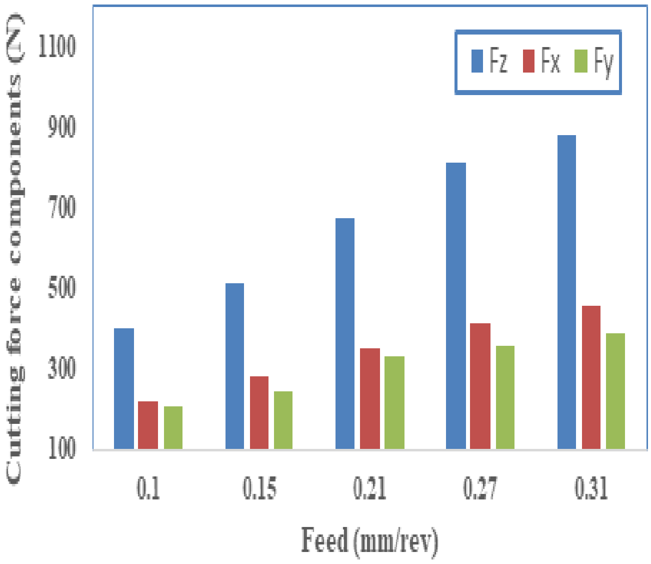


Fig.8. Effect of the feed (f) on the cutting force components at V=19.5 m/min and d=1 mm.

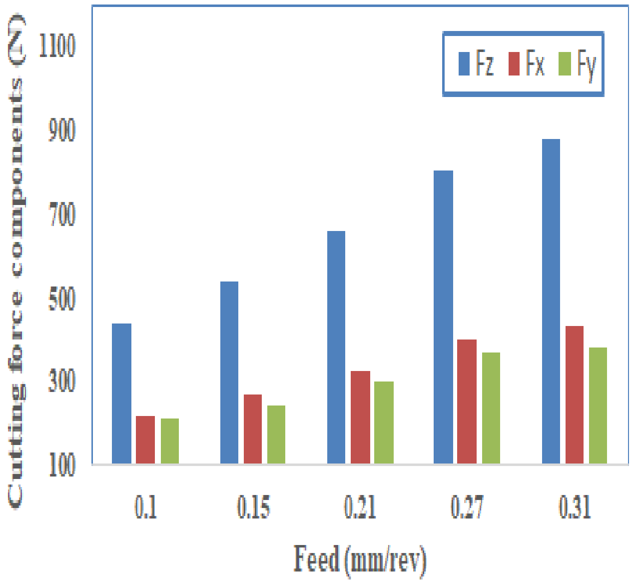


Fig.7. Effect of the feed (f) on the cutting force components at V=12.9 m/min and d=1 mm.

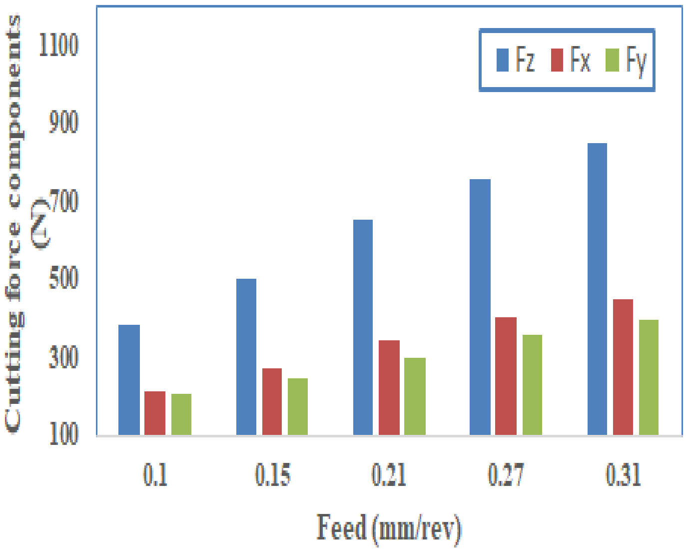


Fig.9. Effect of the feed (f) on the cutting force components at V=29.7 m/min and d=1 mm.

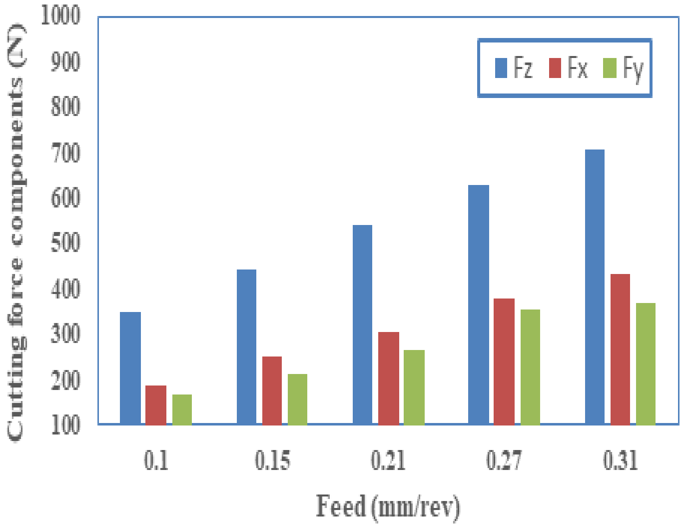


Fig.10. Effect of the feed (f) on the cutting force components at V=49.5 m/min and d=1 mm.

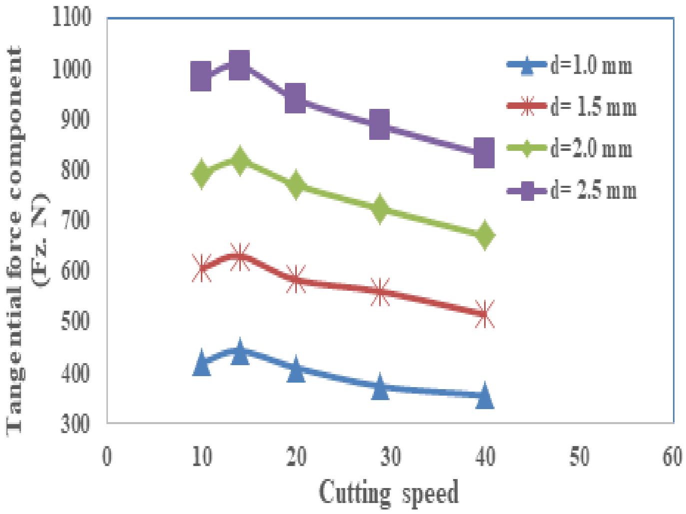


Fig.11. Effect of the cutting speed (v) and the depth of cut (d) on the tangential force (Fz) and f=0.10 mm/rev.

4.1.3 Influence of the cutting speed (V)

The effect of the cutting speed (v) on the cutting force components at different depth of cuts and feeds is shown in Fig. 11 to Fig.13. This effect can be explained by the effect of frictional conditions at the chip tool interface. Starting from low speeds (8~20m/min), the coefficient of friction is relatively large which causes the increases of the cutting force components and there is only a small amount of chip flow along the tool face while the chips are torn out. The internal flow within the chip body leaves the chip underside to the tool face and cases the formation of built up edge (B.U.E). With the increases of the cutting speed (20~50 m/min), the chip flow velocity increases, so that the cutting force are slightly reduced due to the reduction of the coefficient of friction. On the other hand, the increased chip flow increases the cold pressure welding on the tool face.

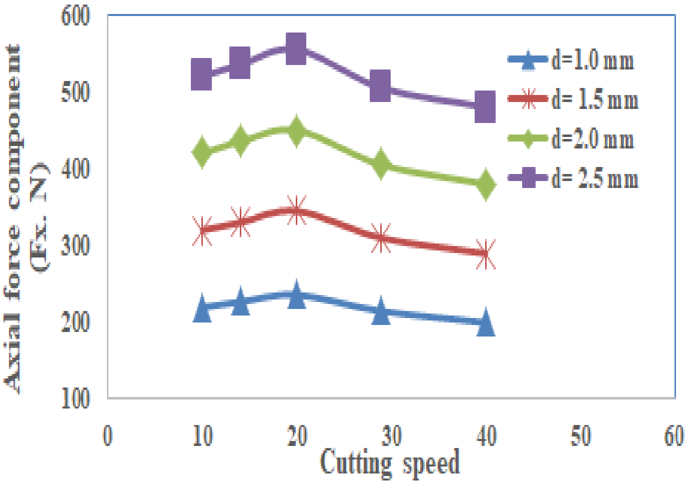


Fig.12. Effect of the cutting speed (v) and the depth of cut (d) on the radial force (Fx) and f=0.10 mm/rev.

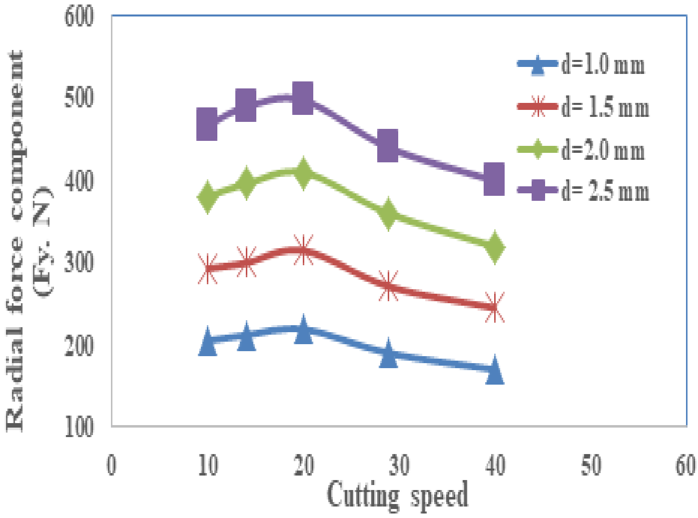


Fig.13. Effect of the cutting speed (v) and the depth of cut (d) on the radial force (Fx) and f=0.10 mm/rev.

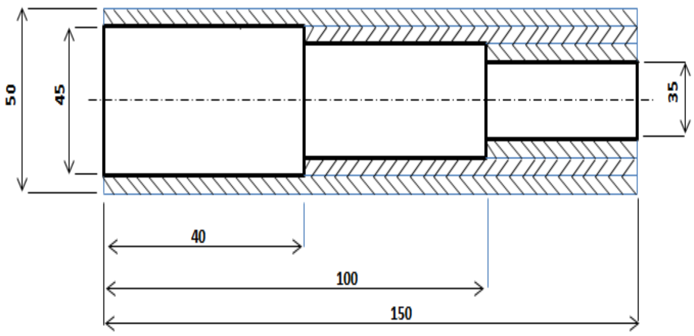
Optimization Results:

As a practical application of the present investigation, the product shown in Fig.14 was used as a case study for the determination of the optimum machining variables which minimize either manufacturing cost or production time. Two methods were used to present the proper technique which must be followed to manufacturing this product. First, the optimization technique was used to determine the optimum machining variables for each stage. If the machining variables are differs from stage to another, the suitable modification is carried out on the machining variables of one stage or more to minimize the total manufacturing cost or the production time.

3.2.1. Minimum Cost Condition:

The output data of the program for the three stages of the product, machined according to the sequence of operations in method (l). It is clear that the depth of cut, feed, and speed (Nw) for each stage are constant and they represent the optimum cutting conditions for all stages. The optimum cutting conditions for the same product machined according to the sequence of operations in method (2). From this table, it is clear that the feed differs from stage to another due to the change in the depth of cut, while the speed (Nw) remains constant. So that, the manipulation time in this method is increases than in method (1) due to the change of feed in each stage. The time required changing the feed or the speed was found to be 15 sec, and was obtained from motion and time study carried out in lathe workshop. The total manufacturing cost for this method becomes 20.67 P.T.

(A)



(B)

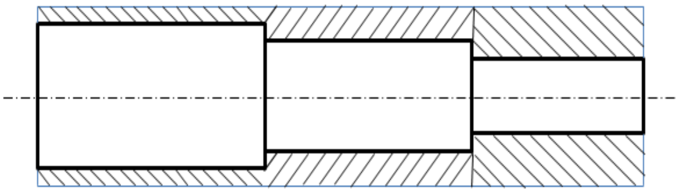


Fig.14. Sequence of machining operation of the product (a) method 1 and (b) method 2.

5. Conclusions and Recommendations:

According to the above results and, it can be followed that:

1. By increasing the machining variables (cutting speed, feed, and depth of cut), the cutting force components were found to decrease with the cutting speed (outside the built-up-edge range), and to increase with the other two variables.

2. It was possible to establish empirical formulae for the determination of cutting force components as functions of cutting speed, feed, and depth of cut.

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