ANALYSIS OF CUTTING FORCES OF THE LATHE TOOL DYNAMOMETER

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ABSTRACT

Current research focused on the assessment of metal machining process parameters and on the development of adaptive control, shows that machine performance, work-piece and tool material selections, tool life, quality of machined surfaces, the geometry of cutting tool edges, and cutting conditions are closely related to the cutting forces. The paper deals with checking the design of lathe tool dynamometer under the capacity of 500 kg and optimization of their cutting force measurement. In this, mechanical gauges were replaced by resistance strain gauges which are being utilized to sense the cutting forces during machining and give the necessary information of cutting forces in terms of resistances which is the measure of cutting and feed forces. The data is obtained using technique of force measurement in metal machining processes. In particular for turning process the results are analyzed, leading to an appraisal of the current status of the cutting force measurements w.r.t. Feed rate, depth of cut and feed/revolution.

INTRODUCTION

A dynamometer is a machine used to measure torque and rotational speed (rpm) from which power produced by an engine, motor, pump or other rotating prime mover can be calculated. In order to put the analysis of the metal cutting operation on a qualitative basis, certain observations must be made before, during and after a cut. Design criteria will be discussed first, followed by a review of several types of force measuring equipments. Hence, it is essential to study the metal cutting process for economical aspects of the manufacture of the components. To investigate the performance of cutting, the measurement of cutting forces is essential. The capacity of lathe tool dynamometer is 500kg, sensitivity is 1 kg, cross interference of 2%, natural frequency is 800 cps (min.) and size of tool is 0.5 inch. Generally, there are three requirements that are always in opposition in dynamometer design are sensitivity (with in ± 1%), rigidity and stiffness. For the purpose of analysis, any dynamometer can be reduced to a mass supported by a spring because all machine tools operate with some vibrations and in certain cutting operations. Recorded forces is not influenced by any vibrating motion of the dynamometer, its natural frequency must be large as compared to the exciting vibrations. In this, mechanical gauges were replaced by resistance strain gauges which involve the deflection with a suitable calibration between the force and the deflection it produces, are being utilized to sense the cutting forces during machining. This gives the necessary information of cutting forces in terms of resistances which is the measure of cutting and feed forces.

DYNAMIC FORCE MEASUREMENT

Tool dynamometers have some additional difficulties since these generally measure orthogonal forces by using electrical dynamometer which involve the use of transducers. The changes in electrical signals are indirectly produced by the tool forces by causing strain or displacement. Also, electric transducer works on the principle of Wheatstone Bridge Circuit. It is evident that in order to measure the strains of the order of 1 in/in., the strain gauge lathe dynamometer is used. It is frequently convenient to reduce the lathe operation to a two-dimensional process. While any two force components may be measured, the most convenient are the axial and the tangential components of force will cause a bending moment at some distance from the cutting edge that will cause a moment on the beam tends to measure the lathe forces.

METHODOLOGY ADOPTED

The study depends upon methodology opted for the proceeding as it decides the way of collecting the data, manipulation, processing and finally the display of the results.

1. Measurement of cutting force by using electrical strain gauge is the best technique available.
2. The machining parameters will be considered during the machining w.r.t. cutting forces and feed forces by predicting the cutting performance such as depth of cut, feed/rev. and speed.
3. The natural frequency of the tool holder of lathe tool dynamometer will be calculated.
4. Stress calculation will be carried out for the safe design of lathe tool dynamometer.

PRODUCT SUMMARY AND OBSERVATIONS AT DIFFERENT DEPTH OF CUT

Cutting force have been measured by using the lathe tool dynamometer (Integral damping by heavy cast iron body) which suit to a wide range of lathes and easily fixed to lathe cross-slide. By the application of cutting tool theory, the effect of various parameters such as cutting speeds, feed and cutting forces on the action of cutting tool by varying the depth of cut has been observed in Table 1. The values of forces exerted on the machine components which affect the geometrical accuracy of work pieces.

Table 1 Cutting Speed and Forces at Different Depth of Cut

Depth of cut, a (mm)	Feed per revolution (mm)	Dia., d (mm)	Cutting speed V = πDn (m/sec)	Force			Speed (rpm)
				Cutting Forces $F_{z(kg)}$	Feed Force $F_{x\,(kg)}$	F, resultant $\sqrt{Fz^2 + Fx^2}$	
0.5	0.0781	21.78	23.25	15	3	15.29	340
1.0	0.0781	20.78	22.19	30	7	30.81	
2.0	0.0781	18.78	18.78	52	20	55.71	
2.5	0.0781	14.78	14.78	58	24	62.76	
0.5	0.046	23.04	20.25	20	4	20.39	280
1.0	0.046	22.04	19.38	42	6	42.43	
1.5	0.046	18.96	16.67	49	9	49.82	
0.5	0.0647	15.90	16.67	15	5	15.8	340
1.0	0.0647	21.04	21.04	32	8	32.98	
2.0	0.0647	23.04	24.59	55	22	59.23	

FREQUENCY CALCULATION

Natural frequency is calculated as follows: Fig. 1 where, deflection at end AB due to load of 500kg. The general equation for the deflection of the beam is:

$$\delta = \frac{M_m}{EI} \times dx$$

For square cross-section, $I_2 = \frac{d^4}{12} cm^4$

For round cross-section, $I_1 = \frac{\Pi d^4}{64}$

$$K = \frac{F}{\delta};\ W_n = \frac{\sqrt{k}}{m} \times g$$

Where

M= Moment; m= Effective mass
K= Spring Stiffness constant; F= Force; δ = Deflection
V = Cutting speed = πDn (m/sec)
F, resultant = $\sqrt{Fz^2 + Fx^2}$
F_x and F_z is noted from the dynamometer indicating units

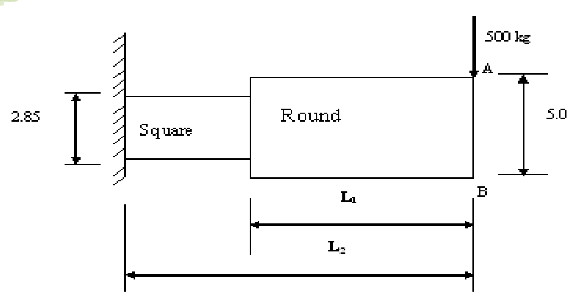

Figure 1: Line Diagram of Tool Holders

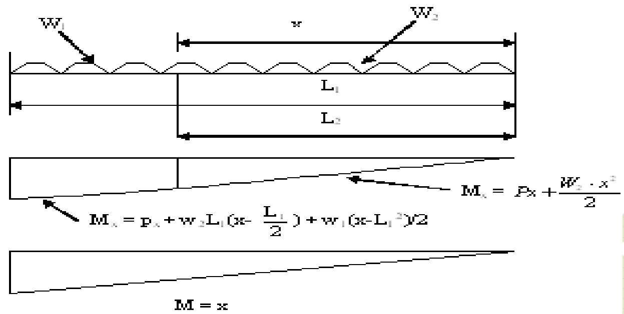

Figure 2: Shear Force & Bending Moment Diagram

Shear force and bending moment are calculated by referring the Fig. 2.

$$\delta = \int \frac{Mm}{EI}dx = \int_0^{l_1} \frac{Mx}{EI_1}dx + \int_{l_1}^{l_2} \frac{M}{EI_2}xdx$$

$$= \int_0^{l_1} x\left\{P \cdot x + \frac{w_2 x^2}{2}\right\} \times \frac{1}{EI_1}dx + \int_{l_1}^{l_2} x\left\{Px + w_2 l_1\left(x - \frac{e_1}{2}\right) + w_1\left(\frac{x - e_1}{2}\right)^2\right\} \cdot \frac{1}{EI_2}$$

$$= \int_0^{l_1}\left(Px^2 + w_2\frac{x^2}{2}\right) \times \frac{1}{EI_1}dx + \int_{l_1}^{l_2}\left\{Px^2 + w_2 l_1 x\left(x - \frac{l_1}{2}\right) + w_1 x\frac{(x - l_1)^2}{2}\right\}$$

$$= \frac{1}{EI_1}\left[\int_0^{l_1} Px^2 ds + \frac{w_2}{2}\int_0^{l_1} x^3 dx\right] + \frac{1}{EI_2}\left[\int_{l_1}^{l_2} Px^2 dx + w_2 l_1 \int_{l_1}^{l_2} x^2 dx - \frac{w^2 l_1^{\ 2}}{2}\right]$$

$$+ \frac{1}{EI_2}\left[\frac{w_1}{2}\left\{\int_{l_1}^{l_2} x(x^2 + l_1^{\ 2} - 2xl_1)dx\right\}\right]$$

$$= \frac{1}{EI_1}\left[\frac{Pl_1^{\ 3}}{3} + \left(\frac{w_2 x^4}{8}\right)_0^{l_1}\right] + \frac{1}{EI_2}\left[\left(\frac{Px^3}{x}\right)_{l1}^{l2} + w_2 l_1\left\{\left(\frac{x^3}{3}\right)_{l_1}^{l_2}\right\} - \frac{w_2 l_1^{\ 2}}{2}\left(\frac{x^2}{2}\right)\right]$$

$$= \frac{1}{EI_1}\left[\frac{Pl_1^{\ 3}}{3} + w_2\frac{l_1^{\ 4}}{8}\right] + \frac{1}{EI_2}\left[\frac{P}{3}\left(l_2^{\ 3} - l_1^{\ 3}\right) + \frac{w_2 l_1}{3}\left(l_2^{\ 3} - l_1^{\ 3}\right) + w_1\left\{\frac{1}{4}(l_2^{\ 4} - l_1^{\ 4}) + \frac{l}{2}\right\}\right] \quad \text{……..(i)}$$

Where,

Density of steel = 7.87gm/cc and Density of stainless steel = 7.93gm/cc

L_1=8cm; L_2=10.3cm; W_1=155.6gm/cm and W_2=64.4gm/cm

W_1 & W_2 are self weight of two sections.

$I_1 = \pi \times \frac{5^4}{64} = 30.6cm^4$ and $I_2 = \frac{2.854}{12} = 5.49cm^4$

Substituting these values in (i), we get

$$\delta = 0.001394 + 0.008756 = 0.01015cm$$

$$K = \frac{f}{\delta} = \frac{500}{0.0102} = 4.902 \times 104 \text{ kg/cm}$$

$$m, \text{effective} = \frac{W_1 \times L_1}{1000} + \frac{W_2 \times L_2}{1000} = 1.245 + 0.148 = 1.393\text{kg}$$

$$W_n = \frac{\sqrt{k}}{m} \times \frac{1}{2\Pi}$$

$$F_n = \frac{1}{2\Pi} \times \sqrt{4.9 \times 104} \times \frac{981}{1.393} = 934.6\text{cps}$$

DESIGN STRESS CALCULATION

Stress has to be calculated by analyzing the dimensions as follows: Fig. 3.

Therefore L = 8 + 1.4 + 1.8 =11.225cm

$$E = 2.1 \times 10^6 \text{ kg/cm}^2$$

$$\sigma = \frac{m}{z} = F_c \times \frac{L}{z} = 500 \times \frac{11.225}{3.858} = 1455 \text{ kg/cm}^2$$

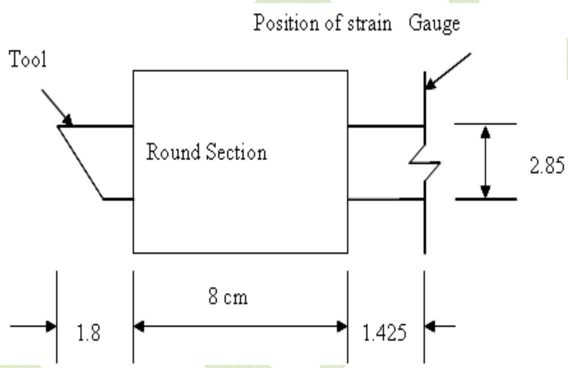

Figure 3: Dynamometer Tool

Stress has been calculated on capacity basis, now force is calculation on the basis of allowable stress for steel. Under repeated loading, the stress, $\sigma = 1840 \text{ kg/cm}^2$ (after taking factor of safety)

Using, $\sigma = F_c \times \frac{L}{z}$

Cutting Force, $F_c = 500$ Kg

Therefore at allowable stress, the cutting force

$$F_c = 3.858 \times \frac{1840}{11.225} = 632.40 \text{ Kg}$$

But cutting forces analysis is to be carried out for the design of 500kg. Therefore at stress, 1455 kg/cm^2, the cutting force

$$F_c = 3.858 \times \frac{1455}{11.225} = 500 \text{ Kg}$$

So, our design is safe for above said forces.

RESULTS AND DISCUSSION

As per observation recorded, the feed forces and depth of cut is directly proportional to cutting forces. All the analysis is shown in the graphs which shows that on increasing the depth of cut leads to increase in cutting & feed force i.e. approximately linear. Also, cutting forces depend upon feed rate of tool so the cutting forces increase as feed rate increases. Cutting forces is also decreases as feed/rev. increases. Moreover frequency & stress produce in tool of dynamometer within given criteria of safe design. These have been as follows: Fig. 4, 5 and 6.

The similarity of the records obtained from the dynamic testing of two-component strain gauge dynamometer indicated good repeatability of measurements. However, the results shows that relatively high variation in the accuracy of horizontal and vertical force components developed due to large effect of cross sensitivity, zero drift, and variations in voltage supply and temperatures. Another difficulty was that differences caused by changes of the sensitivity among the measuring bridges by changing the balance points of the circuits. In practice, the measuring bridges were not stable and caused a number of problems.

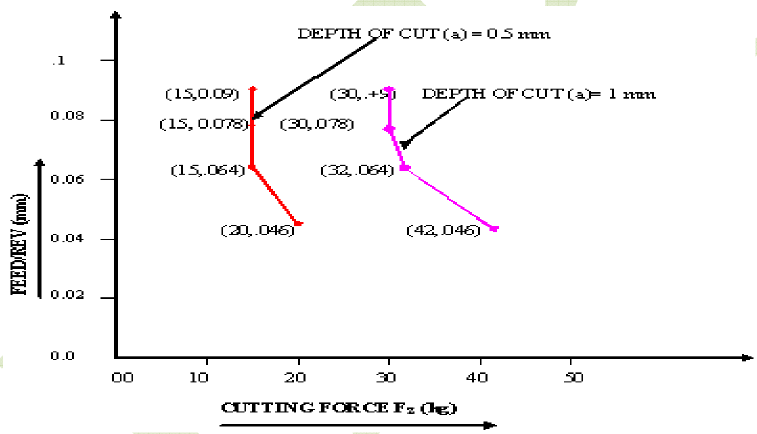

Figure 4: Feed Per Revolution vs Cutting forces

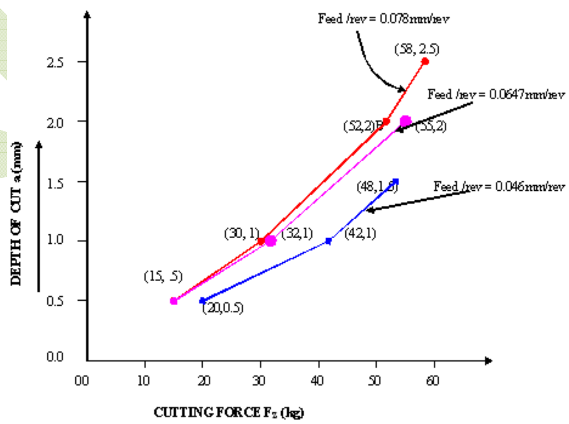

Figure 5: Depth cut of vs cutting force

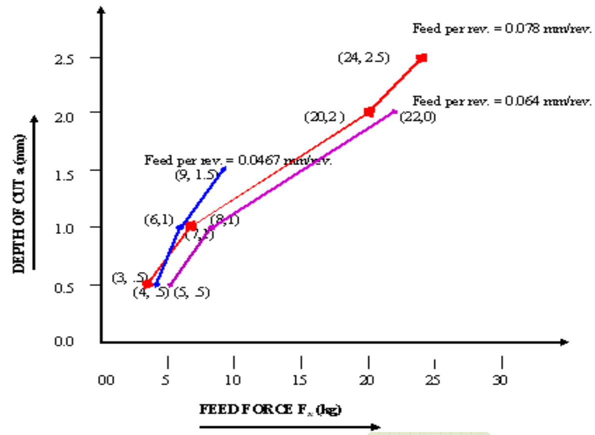

Figure 6: Depth of Cut vs Feed force

CONCLUSIONS

The cutting forces are measured by using electrical strain gauge is the best technique available. As per cutting analysis of forces, it has concluded that the cutting & feed forces is directly proportional to depth of cut & feed rate of tool and inversely proportional to feed/rev. Natural frequency & stress produced in tool of dynamometer has been formulated to give the permissible limits of the safe designs. So the design is safe within given parameters, for which the instrument is made.

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