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INVESTIGATIONS ON CUTTING WITH ROTARY OSCILLATORY TOOLS - A NEW CUTTING PROCESS

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ABSTRACT:

Rotary cutting is a process in which the cutting edge has a velocity V_t along itself, in addition to the usual motions of cutting speed V and feed. Earlier work by the authors has shown that, when V_t/V is properly selected, one can achieve immense benefits like reduction in cutting forces by several times, shear angles greater than 45° etc.

The traditional rotary tools have been circular in form since they use continuous rotary motion v_t. The tool can thus be used only for machining simple workpiece forms. This constitutes the most significant criticism of the rotary concept from the practical point of view. If, however, v_t could be made oscillatory, the limitation is no more valid.

To investigate the effectiveness of oscillatory V_t, two rigs were developed. The first rig used a straight edged tool mounted on a spring loaded tool post and excited by a rotating eccentric. The second rig used a four bar mechanism to oscillate a circular rotary tool about its axis. The frequency was variable in both cases. Tube turning experiments were done.

The results showed that the rotary oscillatory tool (ROT) is capable of achieving all the beneficial effects of continuous rotary tools. Further, the optimum mean V_t/V was much lower. This is attributed to the inertia of the cutting process which results in the chip preferring to float on, rather than oscillate with, the tool rake. The effects are far superior in magnitude to those that are cited in literature for tools using other directions of oscillation.

The experiments also showed a tendency of optimum amplitude of V_t to decrease with frequency. This leads to the possibility of applying low amplitude, high frequency, rotary oscillations while using conventional single point tools. This opens up new vistas, of immense practical significance, of rotary cutting.

1. OSCILLATORY CUTTING PROCESSES

There are a number of investigations using electromagnetic exciters to oscillate the cutting tool in a sinusoidal manner in feed or cutting speed directions, while the carriage of the tool holder is given a constant feed. The cutting force components are found to be less than those with a static tool. It was suggested that the reductions may be due to a reduction in the mechanical strength of the work piece material in the presence of ultrasonic vibration. The tensile and torsion tests to fracture were performed on specimens of the work material while it was being subjected to ultrasonic vibration by Skelton(1). But no reduction of mechanical strength under these conditions was observed and it was concluded that the effect is purely a frictional one. The friction conditions improve when the tool goes out of contact with the workpiece. This explanation seems to be reasonable in view of the investigations carried out by Shaw et. al(2). The shear angle at the entryside was more when compared to that at the exit side in the orthogonal rotary machining experiments conducted by them. The reduction in the cutting forces with ultrasonic vibrations was found to vary between 10 to 15%. However at low cutting speeds the reduction was as high as 50%. The experiments of Skelton reported above are with ultrasonic vibrations in the cutting velocity direction. The surface finish was reported to be better with oscillatory vibration in the feed direction.(3) This excitation has been found to useful in the realisation of regularly broken chips. Skelton(4,5) conducted similar experiments and has reported that the surface roughness, deteriorated.

In the present investigation linear Rotary Oscillations are given to orthogonal tool and Rotary Oscillations to a round tool. Special setups with low amplitude oscillations for orthogonal cutting and with high amplitude oscillations to the round tool were made. The results of the investigations specially with regard to the chip thickness ratios, ε_a, chip length ratios, ε_l, chip width ratios, ε_b, and shear angles, ϕ_n, are reported in the present paper.

The influence of the rotary oscillations was found to be phenomenal and the shear angles have reached almost the barrier from the point of view of minimum normal strain criterion.

2. ROTARY OSCILATORY CUTTING

The influence of rotary speed ratio V_t/V, i.e. the ratio of rotary tool velocity

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to the cutting speed on almost all the parameters of metal cutting have been exciting when the tool was given the conventional rotary motion. The shear angles more than 45° and the chip thickness ratios less than unity were reported.[6] It was postulated later that cutting with rotary oscillatory tools will lead to similar effects.[7] The experimental investigations reported in the present paper have confirmed more or less the above speculation.

3. ROTARY SPEED RATIO IN OSCILLATORY CUTTING

A new interpretation has to be given for the rotary speed ratio in the case of rotary oscillatory cutting. If 'L' is the stroke length and 'N' the number of cycles (double strokes) per minute, one can define the mean rotary speed ratio as

$$(V_t/V)_{mean} = \frac{LN}{V} \quad \text{.......(1)}$$

The mean rotary speed ratio can thus be controlled by two methods i.e. through L (amplitude of oscillations) or through N (frequency of oscillations).

4. EXPERIMENTAL RIGS

4.1 Low Amplitude Rotary Oscillatory Unit

Fig. (1) shows, schematically, the test arrangement used.[8] An eccentric shown in the figure provided the rotary oscillations to the orthogonal tool. A compound D.C. Motor of 2 H.P. with variation of speed between 400-1600 rpm, was mounted on a platform clamped to the cross slide of a Rigiturn Lathe. On the motor shaft a ball bearing was mounted with an eccentricity of 0.185mm. The ball bearing acted like a roller follower of an eccentric cam. A support bracket using ball bearings was mounted to protect the Motor from eccentric loads. On the cross slide specially constructed flexible tool post was mounted. This tool post had two rigid mild steel plates at the top and the bottom which were connected with two flat springs . The top plate had a provision to clamp the tool. When the rigid follower was touching the eccentric, the eccentric motion was transmitted to the top plate of the tool post resulting in practically horizontal oscillations of the tool. The longitudinal feed provided the necessary uncut chip thickness. The workpiece (seamless tube) was clamped in the chuck. The gear box of the lathe was disconnected from the main drive and was connected to a specially installed double reduction drive. The workpiece could be rotated in a speed range 0.75 rpm to 37.5 rpm. The purpose

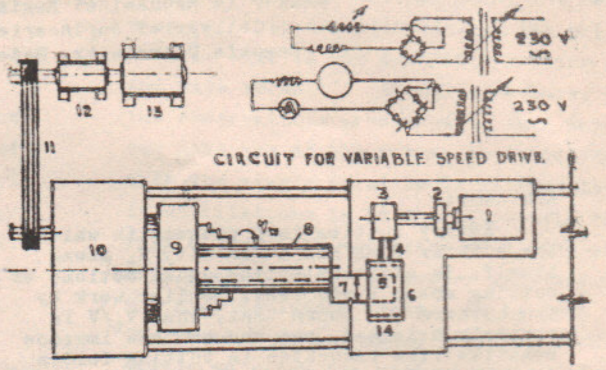

FIG. 1

SCHEMATIC ARRANGEMENT OF THE LOW AMPLITUDE ROTARY OSCILLATORY SET UP

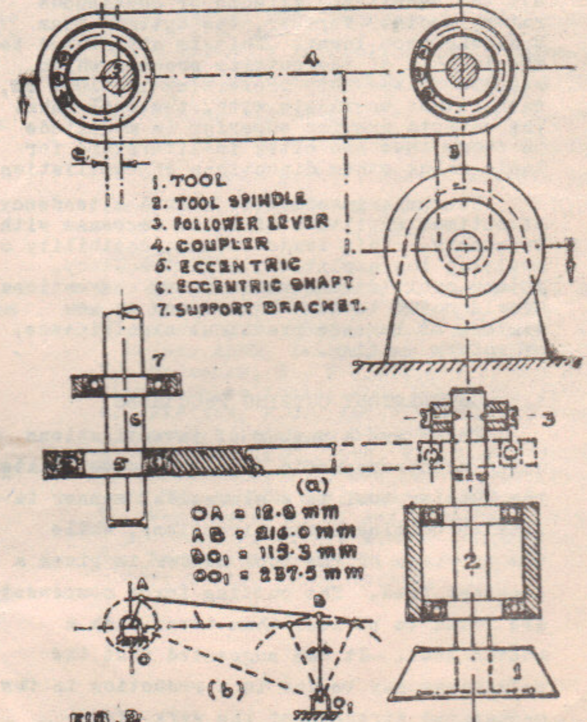

FIG. 2

TEST ARRANGEMENT FOR HIGH AMPLITUDE R.O.T.

of reducing the work speed was to get a high mean rotary speed ratio even at low oscillatory tool speed. In view of the low work speed 'V' carbon tetrachloride was fed carefully through a hypodermic syringe into the cutting zone. Axial slots on the workpiece controlled the uncut chip length 'l'. Cutting was performed at various oscillatory speeds available from the D.C. drive and mean rotary speed ratio values were calculated using equation(1) . The exact amplitudes of oscillations were monitored with a Philips contactless reluctance type of velocity pickup. Chip dimensions l_c and b_c were measured. From these the various kinematic parameters like ϵ_a , ϵ_b , ϵ_l , and ϕ_n were calculated.

4.2 High Amplitude Rotary Oscillatory Unit

In the set up discussed above high amplitude of oscillations could not be obtained due to the flat springs used. Therefore a setup using a four bar mechanism had to be developed. Fig. 2 shows the schematic arrangement of the four bar mechanism used. A tool with a rake angle of 10° was mounted on a rotary turning unit. The rotary unit had a vertical setting angle, θ_v of 15°. The unit was mounted on the cross slide. The position of the cross slide was arranged so as to get an angle of obliquity of 45°. The rear end of the spindle was connected to the follower lever of the four bar mechanism. The lever was driven by a coupler rod, which in turn received its drive from a rotating eccentric. Ball bearings were used at all the pivots. The eccentric was driven by the same D.C.Motor which was used in the low amplitude set up. The motor was mounted on a platform which was inclined to the horizontal plane (cross slide) at an angle of 15°. This ensured that the four bar mechanism was in a plane. Fig.2(b) shows the dimensions of the linkage. The stroke length of the cutting edge (rotary oscillations) was adjustable between 10 to 15 mm by varying the follower lever length. The work drive was same as that used in the low amplitude ROT set up. The work materials namely mild steel and copper were tested. The test procedure was identical to that used in the low amplitude experiments.

5. OBSERVATIONS AND DISCUSSION

Fig. 3 shows the variation of ϵ_a , ϵ_b and ϵ_l , with mean rotary speed ratio as observed in the low amplitude set up. The chip width 'b' was almost constant for all values of mean rotary speed ratio. This indicated

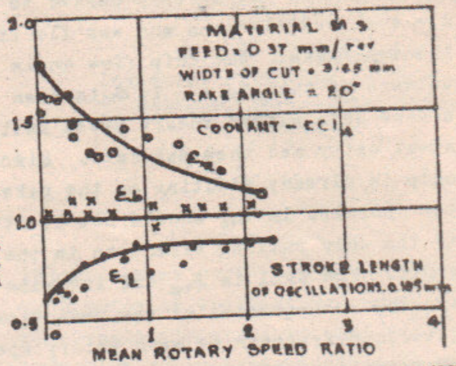

FIG. 3 VARIATION OF KINEMATIC PARAMETERS WITH(V_t/V_W)MEAN WITH LOW AMPLITUDE R.O.T

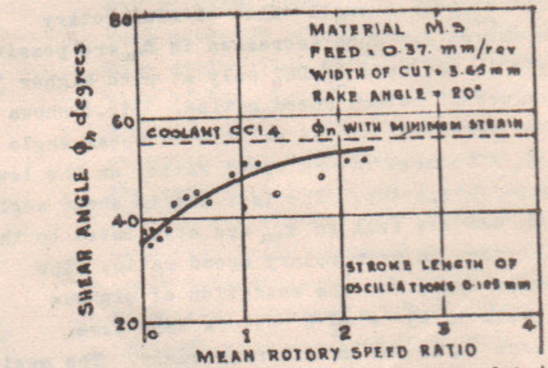

FIG. 4 VARIATION OF ϕ WITH (V_t / V_W) MEAN WITH LOW AMPLITUDE R.O.T.

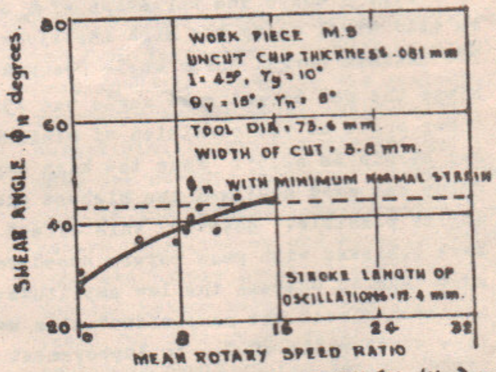

FIG. 5 VARIATION OF ϕ_n WITH (V_t /V_W) MEAN ON MILD STEEL WITH HIGH AMPLITUDE R.O.T

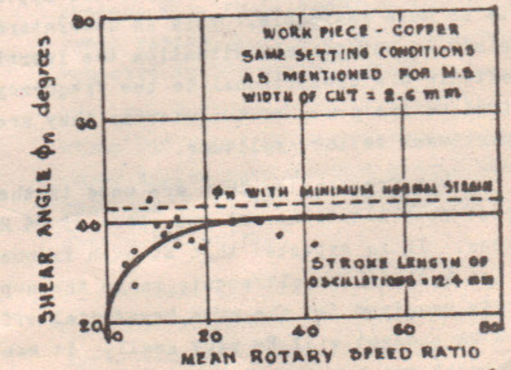

FIG. 6 VARIATION OF ϕ_n WITH (V_t/V_w) MEAN. ON COPPER WITH HIGH AMPLITUDE R.O.T.

that the chip had already ceased to follow the tool oscillations and was floating on the tool rake. The chip flow angle was equal to zero so that $\epsilon_{nb} = 1$. ϵ_{nl} is seen to increase upto a mean rotary speed ratio of about unity and then saturate. Since the chip is already floating on the rake surface the increase in ϵ_{nl} should not be attributed to the chip pulling effect as in the case of a DRT. The fall in ϵ_{na} and increase in ϵ_{nl} are the consequences of the reduction in the interface friction as mean rotary speed ratio is increased. The improvement in ϵ_{na} is comparable to that in the case of DRT. ϵ_{na} has fallen from 1.7 to 1.1. This fall has occured at such a small value of mean rotary speed ratio as 2. Such decreases in ϵ_{na} are possible in the case of DRT only at much higher values of rotary speed ratios. Fig.4 shows the variation of the calculated shear angle ϕ_n with mean rotary speed ratio on the low amplitude setup. The increase in shear angle ϕ_n and the fall in ϵ_{na} are attributed to the increase in mean rotary speed ratio. The shear angle for the condition of minimum strain is $45^\circ + \frac{\gamma_n}{2} = 55^\circ$ in this case, where γ_n is the normal rake angle. The maximum shear angle reached is about 52° which is close to the above.

Fig. 5 shows the variation of ϕ_n obtained on mild steel using the high amplitude setup. The maximum normal shear angle reached was 43°. Since the set normal rake angle was -5° the shear angle at the condition of minimum normal strain is 42.5°. Thus the high amplitude setup has also achieved the highest shear angles possible. However, this effect has been achieved with mean rotary speed ratio of more than 10 whereas the low amplitude setup achieved almost the same effect at a mean rotary speed ratio of 2. An improvement in mean rotary speed ratio, which influences the cutting process, by means of increasing the frequency rather than the amplitude appears to be more desirable. This is understandable since in any dynamic situation the inertial effects are proportional to the frequency raised to the power of two whereas they are proportional to the amplitude.

The frequencies that are used in the present experiments are of the order of 26 Hz or less. It is expected that at high frequencies i.e. in the ultrasonic range the amplitude required for the same beneficial effects to be present will be very small. It was pointed out in an earlier paper that if we consider the rotary oscillatory cutting as viewed in the backdrop of single point tools it would be im-practicable. With the oscilations along the cutting edge, the machining would be transferred from the principal cutting edge to the auxiliary cutting edge and vice versa.[7] At this juncture, due to the observations presented in this paper one can make use of the rotary oscillations even with the single point tools if the frequency of oscillations is in the ultrasonic range. Fig. 6 shows the variation of ϕ_n with mean rotary speed ratio on copper obtained with the high amplitude setup. It is seen that the mean rotary speed ratio of about 20 is needed to reach the highest values of shear angle. This is because the rotary hot-machining effects are not predominant in the case of copper due to its greater heat diffusivity.

It is seen from the above that enormous improvements are possible with the ROT, which are far above the improvements reported from conventional oscillatory cutting processes. Compared to the methods using the oscillatory feed, the ROT is better, as it does not affect either the dynamic rate of metal removal or the surface finish.

6. CONCLUSIONS

Rotary oscillatory machining is more effective process when compared to conventional DRT as much as that it gives all the benefits of the latter at much lower values of rotary speed ratio. The increase in mean rotary speed ratio by increasing the frequency appears to be more desirable compared to that by increasing the amplitude. It may be possible to make use of ultrasonic rotary oscillations to the single pointstools to achieve the same beneficial effects of a DRT.

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