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MECHANIZING THE MANUFACTURE OF STANDARD MASTER CAMS OF COMPLEX CONTOUR FOR MULTI-CUTTER DUPLICATING LATHES

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/Figures are appended./

The most widely used types of equipment for machining complex-contoured camshaft cams and crankshaft journals for airplane, automobile and tractor engines is the multi-cutter duplicating lathe. In output and precision it satisfies the demands of mass production by making it possible to machine all the cams and journals simultaneously.

A special feature of the machine is the complex movement of the cutters during production: in addition to a forward motion in an axial direction and a back-and-forth motion in a radial direction, the cutter also executes an oscillatory motion in the vertical plane, the purpose of which is to preserve an exact or approximate uniformity in the cutting angle of the cutter, thereby assisting clean-cut production.

In all machines for this purpose the complex movement mentioned is obtained through the simultaneous action of two master cams on a system composed of a rest and an oscillating tool holder.

As shown in Figure 1a, the mechanism consists of a guide (1) fastened to the bed of the carriage, a rest (2) with a roller (3) which moves along the guide and is pressed against the master cam (I) by a spring (4). An oscillating tool holder (6) with a roller (7) is held in a groove of the rest at axis (5).

The action of the spring (8) and the cutting force press this roller against the master cam (II). The shafts on which the master cams are fitted are connected by a gear transmission to the spindle of the machine and rotate with the same

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number of revolutions as the spindle. Due to the action of the master cam (I), the rest with the tool holder executes a back and forth motion in a horizontal plane, while from the other cam the cutter holder gets a rocking motion around axis (5) in the vertical plane. As a result of the joint action of the two master cams, the cutter fixed in the tool holder traces the required outline of the part in the plane. Because of the lengthwise motion of this mechanism relative to the machined article, the contour can be machined to any length desired.

The rocking motions of the cutter holders in Figure 1b are transmitted by means of another arrangement of the shafts carrying the master cams, somewhat different, but, in principle, with the same cutter motion.

Until now the designing and manufacture of master cams have presented great difficulties. The construction of profiles (I) and (II) is an extremely tedious operation, demanding the greatest attention and precision; it must be carried out on a fine radial grid on a magnified scale. The points obtained are connected by selected arcs of circles. This first approximation introduces inevitable deviations, and the subsequent reduction of the contours to the natural size in the tracing on metal causes additional distortions.

The production in metal of standards for similar master cams, from which a set of working cams are then produced, entails the operations described below.

By means of a gauge system, standards 10 millimeters thick are prepared point by point (po tochkam). Two standards, produced in this fashion, serve as models, and by duplicating them on a relieving lathe the so-called "master-cams" are prepared. Before heat treatment, the master cams are mounted on a machine for profile checking and finishing.

This operation consumes a great deal of time. Its completion requires an expert gauge maker with a thorough grasp of the kinematics of the mechanism and knowledge of the influence of each element in the profiles of the master cams on the results of the final product.

In organizing the production of duplicating lathes at the "Krasnyy proletariy" Plant and while working out the technological production of "master duplicators," the author tried to achieve the greatest possible mechanization of the labor-consuming processes described and finally worked out a method for producing master duplicators with great precision, according to the known coordinates of the centers of elemental arcs forming the profile of the part. Thus, he completely eliminated these labor-consuming design operations with their inevitable defects, and also manual gauge work in the finishing process.

The theoretical basis for this method and the design of the machine are treated in this article.

All the above kinematic machine systems keep the angle of the cutting edge constant for any point on the circumference, if the cutter in its movement along the part is always located in the same plane, e.g., clamped so that the upper edge of the cutter always remains in plane X--X, passing through the axis of the article as shown in Figure 3a. In other words, the cutting edge of the tool at any cutting point must form a constant angle with the radius of the curvature.

Let us now examine the case where the axis O_1 (Figure 3b) of a rotating body being machined does not coincide with the axis of rotation 0 in a lathe with an oscillating cutter holder. Let us determine, by plotting, the position of the cutter for various points of the profile on condition that the cutting angle of the cutter is kept constant, i.e., the angle formed by the cutting edge and the radius of the profile curvature at each of its points.

50X1-HUM

For a point a, with the axis O_1 of the article being machined located in the plane X--X which passes through the axis of rotation O and has the point a (the cutting point of the cutter), the position of the cutting edge of the tool (at an angle γ to the plane X--X) will be the same as shown by Figure 3a, since for any given point the radius of the profile curvature lies in the plane X--X.

For a position corresponding to a rotation of the part to any angle α, the position of the cutter, while keeping the cutting angle unchanged, is shown by the dotted lines in Figure 3b. To plot this position it is obviously necessary that the line X--X from the center of O_1 should be intersected at the point b_1 by the radius R + A, where R is the radius of the article being finished and A is the left arm of the cutter holder, i.e., the distance from its rocking point to the cutting tip. Points O'_1 and b_1 are joined by a straight line. The point a_1 where this straight line intersects the dotted circle with a point curvature equal to radius R from the center O'_1 determines the position of the cutter tip for a given angle of rotation.

As may be seen from Figure 3b, the cutter occupies the position determined, maintaining a constant angle with the radius of curvature of the profile at this point, i.e., the cutting angle.

During a complete revolution of the blank, the center O_1 of the rotating body describes a circle of radius r equal to the eccentricity (the distance O_1C), and the point b (the axis of the oscillating cutter holder) executes a back-and-forth motion along the straight line X--X with an amplitude equal to 2r, and is displaced at any position by a constant amount R + A from the center of the rotating body, i.e., subject to the same law of motion as a piston in a crank drive.

Moreover, the deflection angles of the oscillating cutter holder will be such that the cutting angle of the cutter fastened to it will be kept constant for all positions of the part being machined.

Hence, it follows that if the oscillating cutter holder is joined with the axis O_1 of the rotating body by a rigid link (guide rod) of length L = R+A and the same axis O' is joined with the axis of rotation O by the crankshaft, the length of which is equal to the eccentricity $\overline{OO_1}$ = r, then this system, for any angle of turn during the rotation of the crankshaft, will determine the positions both of the cutter holder and the rest and, consequently, will determine the trajectory of the cutter during the turning of the eccentric with the axis of rotation O.

Now let us examine what happens to the contour of the cam which is formed by the linked arcs of circles described from different centers during the tracing of the cam, e.g., in Figure 4, the contour takes the following shape: in the section $a_4 - a_1$, a rotating body with an axis coinciding with the axis of rotation O; in the section from a_1 to a_2, a rotating body with a radius R_1 and axis O_1, which does not coincide with the axis of rotation O (see Figure 3b); in the section $a_2 - a_3$, a rotating body with a radius R_2 and axis O_2, also not coinciding with O and separated from it by a distance r'_1. The section $a_3 - a_4$ is analogous to section $a_1 - a_2$. Therefore, the machined contour of this cam is composed of the circular section $a_4 - a_1$ and the three eccentric sections (relative to the axis of rotation O) $a_1 - a_2$, $a_2 - a_3$, $a_3 - a_4$.

By using, for these sections, a system of guide rods and crankshafts of corresponding sizes, it would be possible to force the rest and tool holder system to take such positions in a plane perpendicular to the axis of rotation of the parts that the cutter point would circumscribe the given profile. Figures 5 and 6 show the instantaneous positions of the cutter holder when the cutter is at points a_1 and a_2 of the profile (Figure 4). A diagram under each illustration gives the dimensions of the guide rods and crankshafts.

Figure 7 shows a model built to give a graphic illustration of these conclusions. The model is composed of three disks connected by gear drives with a gear ratio of 1 : 1. The coordinates of the disk centers are assumed to be equal to the coordinates of the axes of the spindle and the two master shafts in the machine. The rest, rollers and oscillating cutter holder are shown schematically on the same scale as the corresponding parts of the machine. The directions in which the disks rotate, indicated in Figure 7 by arrows, coincide with the directions in which corresponding parts of the machine rotate.

Guide rod IV, a continuation of the cutter holder, was made of Plexiglas with holes bored in it in a straight line passing through the axis of rotation of the holder and the cutter tip at distances corresponding to the radii forming the cam profile of the part, calculating from the cutter tip. The profile of the cam to be machined was drawn upon disk III with an axis of rotation coinciding with the axis of the spindle, and holes of the same dimensions as those in the guide rod were made at the centers of curvature of the arcs forming the profile.

Figure 7 shows the position of the mechanism when the guide rod is connected with disk III by a pin passing through the hole in the guide rod at a distance R_3 from the cutter tip and the hole in the disk which is the center of the arc of the profile described by the radius R_2 (arc $a_1 - a_2$ in Figure 4). During rotation of disk III the tip cutter model will move along the required arc, and the rest (slide bar) and cutter holder system will acquire the desired motion as specified above. The intermediate positions of the rollers, traced on disks I and II, will give the required profiles for the master cams in the form of curve envelopes comprising two sets of circles.

At point 5 of the cam profile an arc with a radius R_3 passes through an arc with a radius R_4 which at this point has a common tangent with it. Therefore, at this point it is necessary to change the lengths of the crankshaft and connecting rod (see Figure 4). In the model, this moment is itself determined by the coincidence of the hole in the guide rod, at a distance R_4 from the cutter tip, with the hole corresponding to the center of an arc of radius R_4 on disk III. If in this position the guide rod is connected with the disk by a second pin, passed through these holes which are coaxial at the given moment, and the first pin is removed, then on further rotation of disk III the cutter tip will describe an outline of the top of the cam, and the saddle and cutter holder system will pass through corresponding intermediate positions. By changing, in this manner, the position of the pins in the holes of disk III and in the guide rod and by tracing the positions of the rollers on disks I and II, it is possible to get the whole contour of both cams.

The cam profile shown in the above illustration possesses a certain peculiarity at point 3: this profile does not pass smoothly from arc R_3 to arc R_2 (Figure 8) but instead breaks off. Let us examine two positions of the cutter at this point: first, at the moment of arrival of the cutter along an arc of radius R'_3 at the break point, and, second, at the moment of leaving that point with an arc of radius R_2.

Passing along the arc of radius R'_3 to the break point, the cutter will occupy position I, keeping its cutting angle γ constant (the angle formed by the direction of its cutting edge with a straight line passing through the center of curvature of the given contour section). At the moment of leaving this same break point while starting on its path along an arc of radius R'_2, if it is to keep the cutting angle constant, the cutter must take position II. Therefore, to keep this angle constant in passing through this point, the cutter must rotate through an angle around its tip. There are no practical difficulties in making this turn. At this point holes were made in the guide rod and disk III through which these two parts of the model were connected.

The break point of the profile can be considered an arc of radius zero. The rotation of disk III continues as long as the hole in the guide rod located at a distance equal to R_2 from the tip of the cutter does not coincide with the hole in the disk corresponding to the center of the arc R'_2. The rest and cutter holder system, meanwhile, will also complete a certain movement, and the successive positions of the rollers traced on disks I and II will give the corresponding contour sections of the master cams.

From these statements it is obvious that:

1. To manufacture complex master cams it is not necessary to plot them out
2. Production of such cams in metal can be mechanized.

In some cases the master cams, I and II, obtained by the above method, somewhat distort the part's contour at the transition points from the side radii to the radius at the tip of the cam when this radius is small. In such cases, the contour of the master cam II is obtained from the break points clearly shown at these places (Figure 9): the contour curve in section A has a steep pitch and a sharp transition in its drop toward section B. As the roller is not a point but has definite dimensions the tip is flattened somewhat.

In its course along section A, the center of the roller, at the position of the latter corresponding to the break point of the profile, must be located at point 0 and must rest upon section A at point a. But this point does not exist since it is cut off by the roller movement along section B; in practice, the roller on approaching the junction point of arcs A and B begins to roll across this point, and the center of the roller will not reach the theoretical point 0 by a certain distance X (Figure 9). This produces a less angular rise in the cutter tip, and its premature transition during a certain angle of rotation of the part being machined causes distortions in this contour section of the part. Although this distortion occurs in a very small section and is insignificant in amount, it is desirable, nevertheless, to eliminate it.

Theoretically this can be done only by decreasing the diameter to zero; but even if this were possible (in practice, of course, it can only be approximated), it would be necessary to substitute slide friction for rolling friction, with a sharp edge on the contour of the cam, thereby causing it to wear out rapidly. In practice it has proved possible to compensate for such an error in profile II by correcting the corresponding part of profile I.

The production of the first pair of standards showed all the advantages of this method. The working cams did not need any finishing and produced the given profile accurately. This method makes it possible not only to reduce greatly the period of manufacture for the machines but also to produce, for previously manufactured machines, sets of cams which correspond to new profiles for the parts.

The former difficulties in producing standards have completely disappeared, since there is no need for plotting or gauge finishing.

Some samples of similar machines have already been built for various types of duplicating lathes.

A machine will soon be produced for profiling cams for automatic machines, built on an analogous principle of mechanization of the motion of a grinding wheel on the principle stated, as well as a machine for profiling a master cam with a closed complex curve for a profiling machine used for machining grooves in pilger (pipe) mills.

[Appended figures follow]

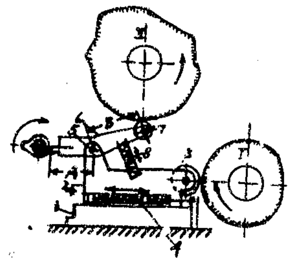

Figure 1a

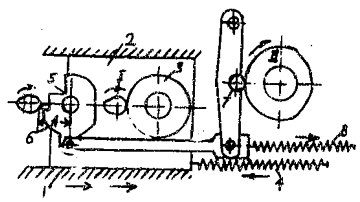

Figure 1b

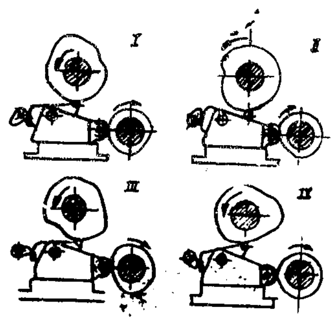

Figure 2

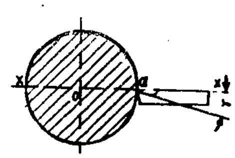

Figure 3a

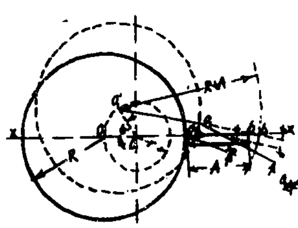

Figure 3b

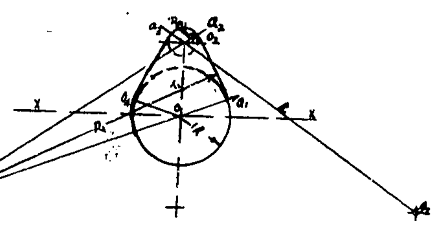

Figure 4

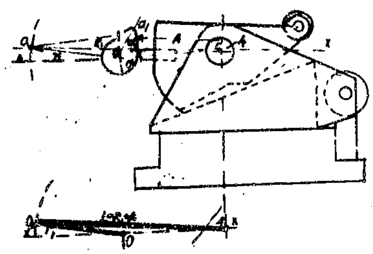

Figure 5

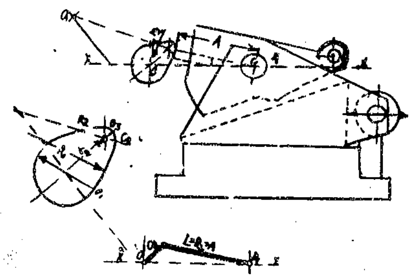

Figure 6

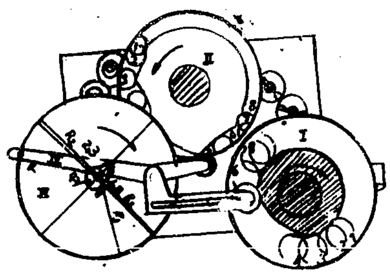

Figure 7

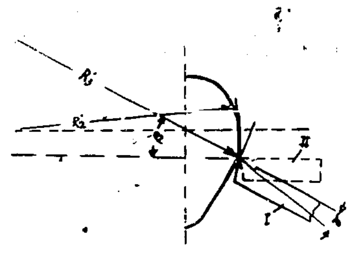

Figure 8

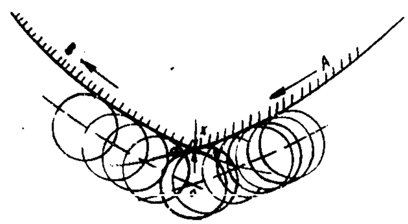

Figure 9

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