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Performances and shapes of acceleration-deceleration curve of kinematical linkages

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Abstract: The transient duty has a very important role within the kinematical linkages of the numerical control machine tools and industrial robots. The acceleration and deceleration of the movable element of the kinematical linkage participates directly to achieving the positioning accuracy and to the path error. This work presents the main shapes of the acceleration- deceleration curve of the kinematical linkage, as well as their performances. Shapes of the acceleration-deceleration curve are presented for positioning linkages as well as for contouring linkages. The extent of influence upon the contour error in case of the linear and exponential acceleration-deceleration of kinematical linkage is also presented. The works is also giving recommendations on the way of choosing the type of curve being used in case of various transient processes, by the machine tool builders, with a view to obtaining high dynamical performances. In general, the recommendations are considering the inertia of the mobile element and the imposed path error. By knowing the acceleration shape, the machine tool designer and builder can know, even from the design stage, the area of the transient duty where the acceleration is maximal. The maximum acceleration imposes the rate of the impulsion torque of the drive servomotor based on which the kinematical linkage is sized, in terms of its components.

Keywords: Kinematical linkage, acceleration, deceleration, transient time, accuracy,

I. INTRODUCTION

The manufacture and usage of a numerical control machine tool are raising a series of new problems that consist not only of the mounting of the CNC equipment but of modifying several parts and sub-assemblies such as to suit the new requirements, demanding more and more.

The influence of the transient time on the path error is a very important problem, along with the problems of obtaining a high positioning accuracy and a good stability of the respective axis.

Knowing the behavior during the transient time, in function of the friction coefficient of the slide-guide way system, the stiffness of the kinematical linkage, its dead stroke, thermal deformations, measurement system, etc. is a very delicate problem.

If, in case of the feed kinematical linkage of positioning and linear machining the transient time does not require special conditions and gives the possibility for obtaining the axis stability through a long response time as the only parameter is the positioning accuracy, in case of the contouring feed linkage there is the behavior at the transient time that comes up in addition, where the requirements of the kinematical linkage are much higher.

The transient time of the numerical control machine tools is expressed through a acceleration-deceleration curve. The machine tool builder imposes these curves and the mechanical designer does their choice from a wide range of possibilities offered by the numerical control.

II. SHAPES OF THE ACCELERATION-DECELERATION CURVE

The shape of the acceleration-deceleration curve of the feed kinematical linkages must comply with two conditions: to shorten the transition time between speed rates, to eliminate the oscillations. In case of the positioning feed linkages, the transient time may take various forms, starting from a fast response with a damped oscillation of the position, Fig. 1, to a slow response with fixed step, Fig. 2. In case of the transient time with damped oscillation, sequent commands based on the reverse response are determining the slide to tend towards the specified position. The version of fast response with accepted oscillation requires a demanding kinematical linkage, in mechanical terms, with a short dead stroke for oscillation damping. As for the positioning feed linkages the only parameter is the positioning accuracy, the transient time can be slow, allowing less requirements on the mechanical part of the feed linkage.

This possible by moving the slide to the end point, by commanding the decrease of the speed rate through fixed values. The initial speed, V_1, is decreased at a certain position of the command while the slide is getting close to the final position, and the next speed rate decreases.

The response of such a system is shown in Fig. 3. This eliminates the possibility of reversing the speed at the final stage of positioning.

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On contouring feed linkages, the response at transient time should be as fast as possible and no oscillations are accepted, either.
This condition results from the fact that the transient time is encountered during the cutting process.

As most of the numerical control machine tools are provided with contouring, the analysis of their feed linkages is needed, in terms of transient time.

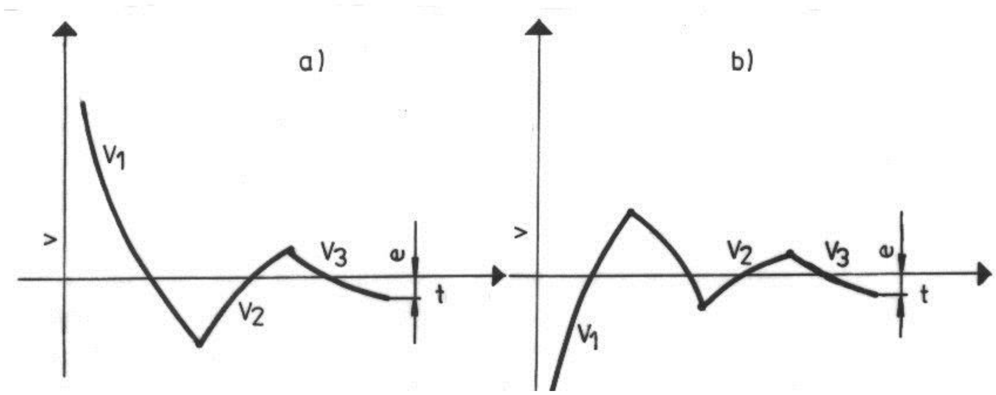

FIg.1 a) Response with over-oscillation; b) Response with over-oscillation from the same direction, for backlash take-over.

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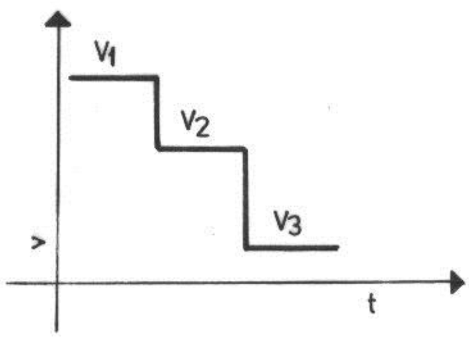

Fig.2 Fast response with a damped oscillation of the position.

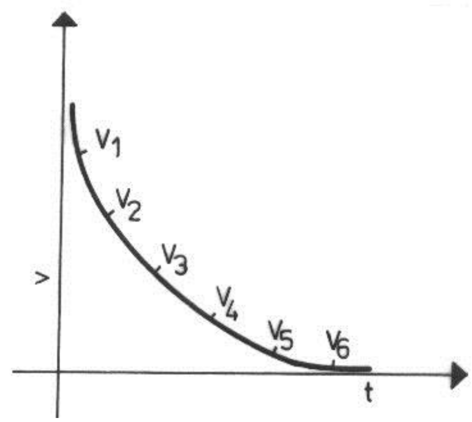

Fig.3 Moving the slide to the end point, by commanding the decrease of the speed rate.

Beside the contouring operations, the same linkages are performing positioning. The requirements of the mechanical part of the feed linkage concerning the dead stroke are high if compared to the positioning feed linkage.
The shape of the acceleration-deceleration curves provided by the numerical controls currently have a various configurations, giving the machine tool mechanical builder the possibility to choose the preferred curve, in terms of response time and stability of the respective linkage.
The shape of the acceleration-deceleration curves mostly used by the manufacturers of numerical controls can be: linear, exponential, hyperbolical or combined. Under permanent duty, the frequency converter provides a maximum limit of current to the servomotor, equivalent to the overload torque.
During the transient duty, the overload torque is ignored for 200 ms. During this period, the acceleration curve established through the machine data is imposing the rate of the torsion torque of the servomotor. This is denominated switching torque.
The rate of this torque on a.c. motors is 4-6 times the rated torque, Fig. 4.
The acceleration-deceleration curves provided by the numerical controls can be easily modified by means of several parameters/machine data that are fixed by the machine tool designer.

Since the oscillation of the kinematical linkage generated by the presence of the dead stroke within the closed loop is crucial for establishing the shape of the acceleration-deceleration curve, the physical aspect of this influence will be presented further.
Upon receiving the command for slide motion, at a lower rate, several mechanical components (servomotor included) are moving, but the final element has no motion. Thus, after a time of dead stroke accumulation, the servomotor can provide a n increased speed, causing the over-oscillation. It is also important the speed of position input (creeping speed), so that the inertia of the kinematical linkage is low, as it is not to exceed the final point of positioning.

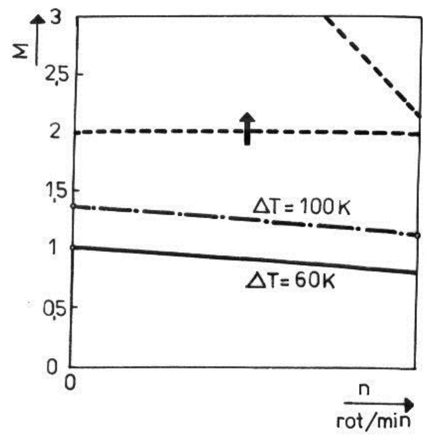

Fig.4 The rate of the torque on a.c. motors.

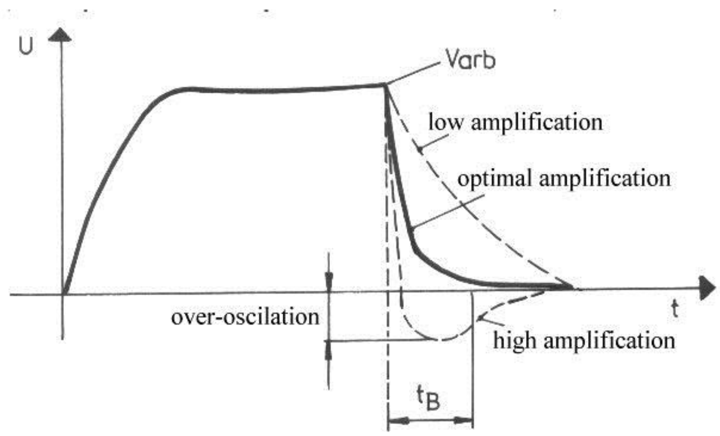

Fig.5 The way of exponential deceleration of a slide.

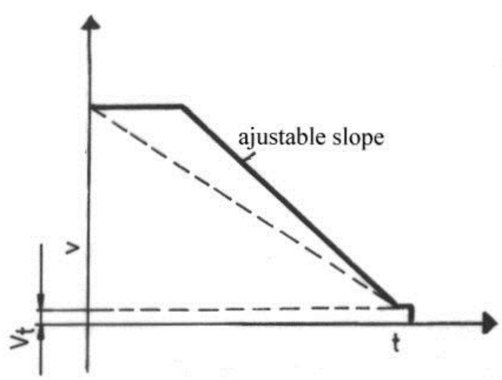

Fig.6 The linear curve having the acceleration slope .

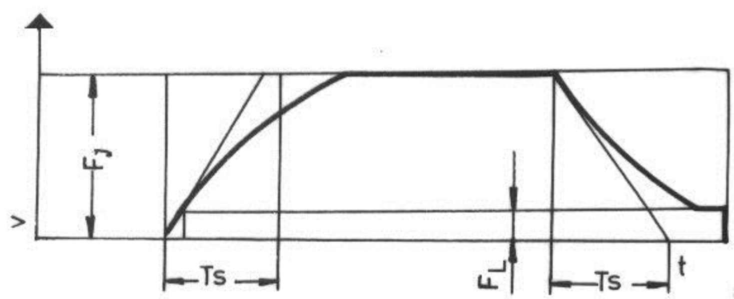

Fig.7 The acceleration –deceleration curve of the controls.

Fig. 5 shows the way of exponential deceleration of a slide, where, by changing the parameters by the machine tool builder, an optimal deceleration can be obtained, thus avoiding the oscillation. In case of the small and middle size numerical control machine tools, the linear acceleration-deceleration is used. This curve has performances superior to the exponential curve, but requires higher demands with regard to the dead stroke of the feed linkage. Practically, on most of the numerical control machine tools acceleration-deceleration curves of linear, exponential or combined type are used.
Fig. 6 shows the linear curve having the acceleration slope and the creeping speed V_t of position input, as adjustment parameters.
By establishing a fast slope, the slide stroke having the speed rate V_t, remains lower, with a view to removing the likely oscillations caused by the dead stroke. On small size numerical control machine tools, where the dead stroke is short, this linear transient duty is successfully used.
The manufacturers of numerical controls such as Siemens, Fanuc, Telemecanique are making use of the two types of curves within the structure of the numerical controls, i.e. linear and exponential, parameterized. The acceleration – deceleration curve of these controls is shown in Fig. 7. They have a low speed and constant rate, F_L, for position input whose rate is established by the machine tool builder.
The transient times having the acceleration-deceleration into a linear-exponential combination have superior performances in terms of response time and stability.
For instance, the numerical controls of type Selca and Heidenhain have acceleration-deceleration curves as shown

in fig. 8. These curves have the following parameters that are to be fixed by the machine tool builder:

- TOL: Tolerance of the fixing limit;
- DE: Deceleration at low speed up to exponential deceleration;
- VLN: speed on slow stroke;
- DEX: Distance of exponential deceleration;
- ZLN: Slow stroke distance;
- DEC: Deceleration up to the slow speed;
- FED: Maximum federate on the axis;
- ACC: Axis acceleration.

The diagram in Fig.8 a is intended for positioning feed linkages where a dead stroke exists, whose negative effects are annulled through the parameters ZLN and VLN. On contouring feed linkages the diagram shown in fig.8 b is used, with parameters adjusted so that the transient duty to be optimally established in function of the mechanical performances. It may be noticed that the usage of the exponential deceleration is encountered at the last stage of positioning with a view to annulling the oscillations.

The Heidenhain numerical controls have diagrams similar to the ones of Selca, with the mention that at the end of the transient time the parameterized exponential curve can be inserted. Some other relevant references can be found in [6], [7], [8], [9], [10, [11].

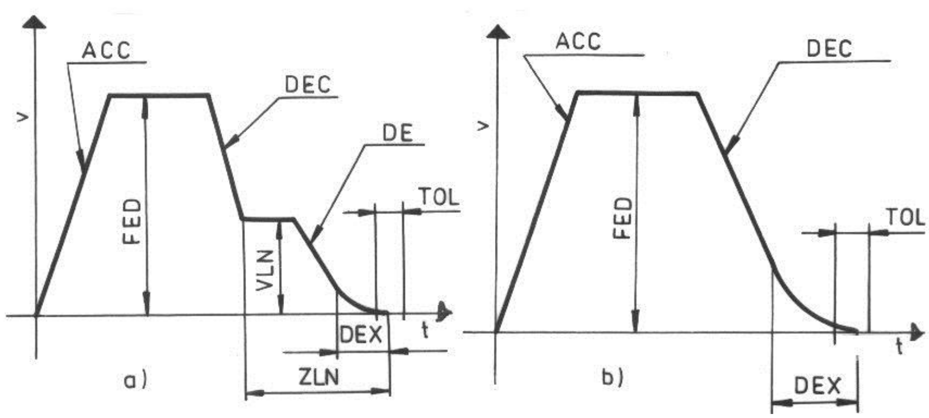

Fig.8 Positioning feed linkages where a dead stroke exists.

III. CONCLUSION

While deciding on the best response of the feed linkage, two criteria can be applied: the system should rapidly respond to a given input signal, the oscillation around a static status should be minimized in case of the positioning feed linkage and eliminated in case of the contouring feed linkage.

In case of the contouring feed linkage, the presence of a slight over-oscillation is unacceptable since, while contouring, the oscillations will be modifying the required profile and the roughness of the machined surface, too.

The designer/builder of numerical control machine tools has the possibility to establish the response times of the axes, by starting from the rate of the path error and the cutting duty. With the help of these response times, he can establish the acceleration-deceleration. By knowing the acceleration-deceleration rates, the rate can be found out of the torsion torque of the of the drive servomotor during the switching time. Through this torque rate the kinematical linkage will be sized, depending on the dead stroke being imposed. In case of using the exponential acceleration-deceleration, the maximum rate along the transient time should be found and, depending on this rate, the torsion torque of the servomotor will be established, that will size the feed kinematical linkage. The machine tool designer should achieve an equalization of the response times of the axes taking part to interpolation, with a view to minimizing the path error. In case of the linear response, the acceleration rates of the axes taking part to interpolation should be equal that requires an optimization of the kinematical linkage sizing just from the designing stage. On several machine tools including controlled axes of high inertia to their structure (such as column movements), the location of such axes is considered such as to not take part to interpolation.

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