THE BACKLASH COMPENSATION OF A FEED KINEMATICAL LINKAGES OF THE MACHINE TOOLS CNC

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Abstract: The high accuracy of the numerical control machine tools especially of the machine tools performing interpolations requires new conditions that have to be fulfilled by the feed kinematical linkages. The aim of this paper is to systemize the compensation systems being used by the machine tool builders, showing the advantages and disadvantages of each one. The relation of the kinematical linkage to the numerical control equipment is also considered, as well as the electronic compensation possibilities of the latter.

Keywords: kinematical linkage, machine tool, interpolation, feed, accuracy.

1. INTRODUCTION

The backlash compensation of a feed kinematical linkage can be performed electronically, mechanically or through a combination of both. The electronic compensation is simple and safe, providing increases of the positioning accuracy. Most of the numerical controls have this function. In case of the feed kinematical linkages used for contouring through interpolation, the path error cannot be improved, since the transient duty is the same. By knowing the diagram of the positioning error in function of the movement of the movable element of the kinematical linkage in one direction and reverse, the rate of the mechanical backlash can be established when changing direction. If this backlash only results from systematical errors, it can be inscribed in the machine data of the numerical control that will be issuing an additional number of pulses, equivalent to the mechanical backlash.

2. COMPENSATION SYSTEMS OF BACKLASH

Through the analysis of the systems used by the NC machine tool builders it results that the usage of the mechanical backlash compensation is mostly encountered on kinematical linkages having the pinion rack set as the last element of transmission. These compensations are performed, in mechanical terms, rigidly and elastically.

a) The version of rigid compensation does not totally eliminate the backlash because of the various errors (radial runout of the gears, pitch errors of the gears, etc.) that minimize it.

Fig. No. 1 shows a feed kinematical linkage used on grinding machines, where the backlash take-over on the first transmission ratios is performed through a double transmission of gears, relatively moved through an eccentric. The transmission ratio on this portion is Z=40 / Z=80.

The movement is transmitted further through a duplex type wormed gearing of a transmission ratio Z=1/Z=60. The duplex wormed gearing, through its design, can take the gearing backlash.

The movement goes on to the final element of the kinematical linkage through a rack and pinion. For the backlash to be taken from this gearing a double linkage is also used, i.e. two racks with inclined teeth, "V" placed, and two pinions. By the relative and axial motion of the two pinions, the gearing backlash is decreased.

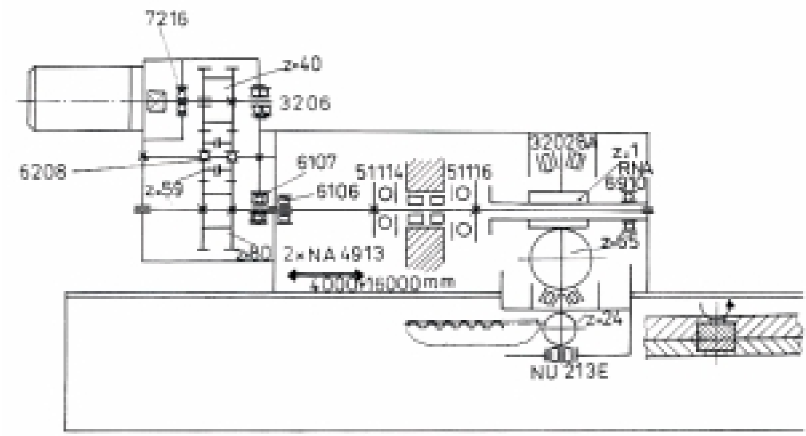

Fig.1. Kinematical linkages with rigid backlash take

The presence of two racks in the kinematical linkage structure makes this solution be expensive and consequently, less used.

A similar backlash system, mainly used on the kinematical linkages rotating the table, consisting of a double linkage, is shown in fig. 2. One branch of this linkage consists of the gears 3, 5 and 8, and the other one of the gears 3, 4 and 6. The backlash take between the two branches is performed by means of the eccentric 7. The motion is further transmitted through a duplex wormed gearing, composed of the wormed shaft 2 and the wormed gear 1.

b) The version with elastic backlash take has the advantage of a total elimination of the gearing backlash, but the transmission efficiency is decreased and, by default, the machine life is shortened.

When using the elastic backlash take version, the condition of below has to be complied with:

$$F_p \geq F_r$$

Where: F_p is the pre-stressing force for backlash take

F_r is the resistant force (friction force and cutting force)

As drive systems for backlash take, the most used consist of hydraulic and disk spring types. Fig. 3 shows the backlash take system being used on large sized bridge type milling machines, especially in case of the table feed linkages. In this case, the kinematical linkage has two branches as well, that are to be pre- stressed

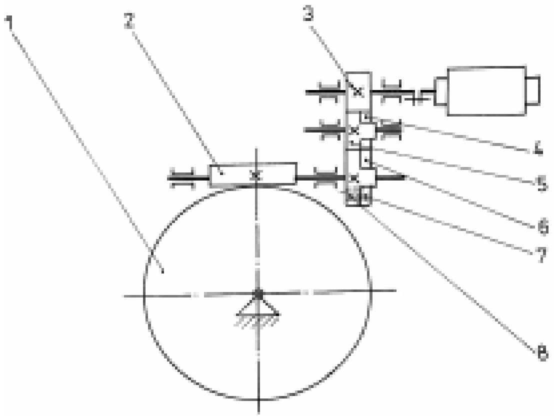

Fig. 2. Rotary kinematical linkage with rigid backlash take-over

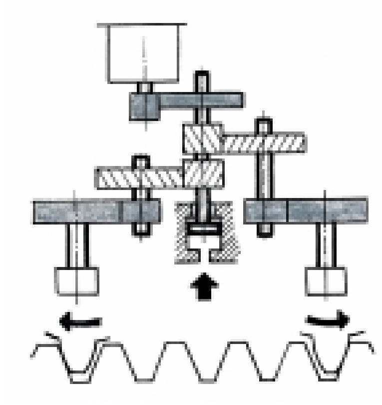

Fig.3.
System of backlash takes with hydraulic drive

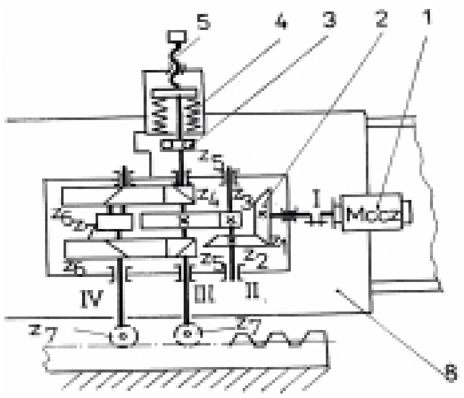

Fig.4.
System of backlash take with disk spring drive

by hydraulic cylinder. Upon the axial motion of the hydraulic cylinder piston, the two pinions that are mounted on the same shaft and have inclined teeth in opposite directions will rotate to opposite directions, thus driving the two branches of the linkage, up to annulling the gearing backlash.
It may be noticed in the figure that the pinions gearing the rack (mounted on the movable element) make contact with one flank only of the teeth. The first set of gears of the driving servomotor has not the backlash taken over. This is explained by the fact that this backlash is decreased by the total ratio of the of the linkage portion and finally has a very low value at the final element of the linkage (the rack).
A system similar to the mentioned above one is shown in fig. 4. Here, the axial motion of the two pinions is given by a pack of disk springs. In this case, the entire linkage is located on the movable element 8. The linkage has tow branches having the pinion Z7 as final element. The disk springs 4 are pre-stressed by means of the screw 5 that moves axially to different directions, through the thrust bearing 3, the two pinions with inclined teeth. Finally, the two pinions Z7 will rotate to opposite directions annulling the backlash in the gearing. Similarly as above, the first gearings 2 of the servomotor 1 are not provided with backlash take, as their low influence is acceptable.
All backlash take systems have to be analyzed in relation to the clamping system of the movable element, as well as to the guiding system being used (hydrostatic, rolling or sliding type).

3. THE ELECTRONIC COMPENSATION OF PITCH AND BACKLASH ERRORS USED ON NC MACHINE TOOLS

The new numerical controls are offering the machine tool builders several compensations and corrections sometimes being relevantly helpful with improving the machine tool performances.
For a feed kinematical linkage, the numerical controls provide the following types of compensations and corrections:

- Pitch corrections;
- Linkage backlash compensation, measured on the final element;
- Thermal compensations;
- Mutual corrections on the mutual position of two axes.

The current numerical controls are using as compensation system for the ball screw pitch errors, more than 1000 points, in both motion directions.
Due to this manner of compensation, with different rates in the two directions, the difference between rates related to the same position means the backlash compensation that is automatically performed. Thus, the backlash compensation is done in more than 1000 points and each point has a different rate.

Fig. 5 shows the error of a ball screw and the dot line means the pitch error after compensation in only 18 points. It is obvious that in this case, the error has been decreased four times, as only 18 points are used.
Other numerical controls are providing the possibility for inserting the electronic backlash compensation, of a limited number of backlash rates on various lengths. Accordingly, fig. 6 shows five rates of backlash that are established for certain rates of the movable element travel. Any direction reversal of the movable element motion, the related backlash compensation for in the respective travel area will be automatically inserted.

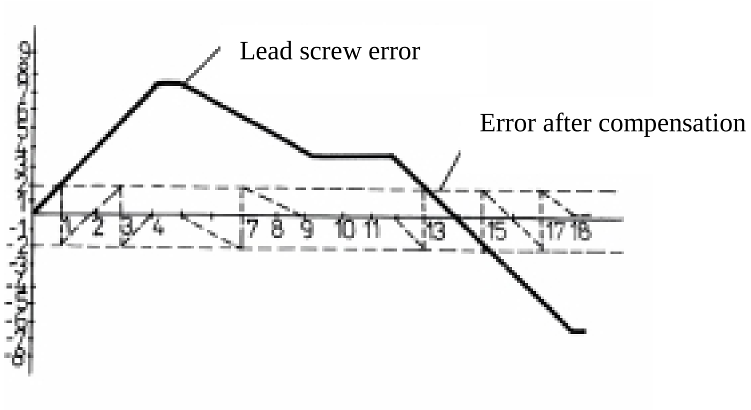

Fig.5. Electronic compensation of the pitch errors

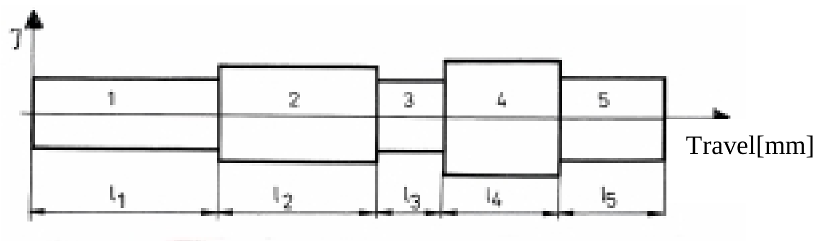

Fig.6. Electronic backlash compensation.

4. CONCLUSIONS

The backlash itself is composed of the backlash between flanks in case of gearings, the backlash caused by the lack of contact of the coupling elements (such as gears-shaft, motor – shaft, etc.) that occurs to the reducers of within the linkage structures.
In case of the feed kinematical linkages using the rack-pinion set as final element, because of the much higher rate of the needed transmission ratio, the backlash rate will also be higher. The positioning linkages are less demanding in terms of backlash, as there are electronic methods for compensation.
The contouring feed linkages are very sensitive, as any inaccuracy may be found in the tool path. Even very low backlash and elastic deformation rates are intending to accumulate while changing the motion direction of the movable element. Therefore, the choice of the backlash compensation system has to be carefully done.

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