

The IBM SELECTRIC Composer

Development of the Rebound Governor

Abstract: Rebound of the escapement system of the SELECTRIC Composer after escapement is limited by the rebound governor, a device consisting of an overrunning clutch and a mass that is coupled to the system only during rebound. The development of the rebound governor is described in this paper and its effect on the escapement system is shown by oscilloscope traces of system displacement versus time.

Introduction

To achieve proportional escapement, the SELECTRIC Composer depends on the fact that the pinwheel in the escapement system comes to rest with a set pin against a fixed stop. If the escapement system is seen as a freely rotating mass pushed by a soft spring, and the "fixed stop" is seen as a stiff spring, the conclusion is drawn that the system will not immediately come to rest after escaping, but rather will rebound away from the stop with a long, slow excursion. To obtain a predictable escapement at any operating speed and to meet various timing requirements at high speed, the amount of rebound must be limited. This is accomplished by the rebound governor, which consists of a mass, or inertia, attached to the leadscrew (Fig. 1) through an overrunning clutch. When the escapement system rotates in the escapement direction, the clutch overruns (Fig. 2) and the system "feels" only the light frictional torque of the clutch. In the rebound direction, the clutch couples the governor inertia to the system inertia. Consequently, the energy which is returned to the system after the impact at the end of escapement is divided between the system and the governor, and the amount of rebound is greatly diminished because of the mass added by the governor.

Specifications for a rebound-limiting device required that the pinwheel rebound be maintained within two degrees during pin-setting operations and that the leadscrew be stationary during print. (The timing sequence and dynamics are such that if the former is met, the latter is also.) Only a minimum of inertia and drag torque, of the order of one inch-ounce at the leadscrew, could be added to the escapement system, and the backspacing of the system could not be restricted. As with any design, the device had to fit the space available and meet reliability criteria.

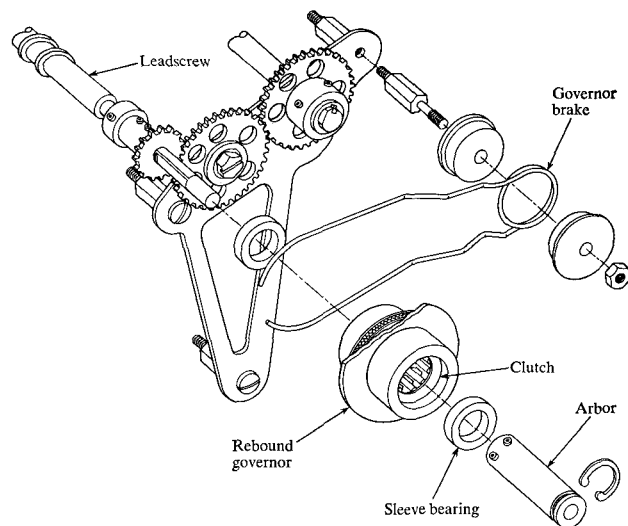


Figure 1 Rebound governor assembly.

Several means of limiting rebound were considered, but did not go beyond the discussion stage. Perhaps the most obvious would have been to use the pinwheel as a ratchet, with a "rebound" pawl designed to allow motion in the escapement direction only. This could provide a very positive rebound control, but would have caused noise as the pawl chattered over the pins during escapement, or would have required the design of a mechanism for lifting the pawl during escapement, then dropping it into the pins at the precise moment to catch the rebound. In either case additional hardware, probably a special mechanism, would have been needed to allow backspacing.

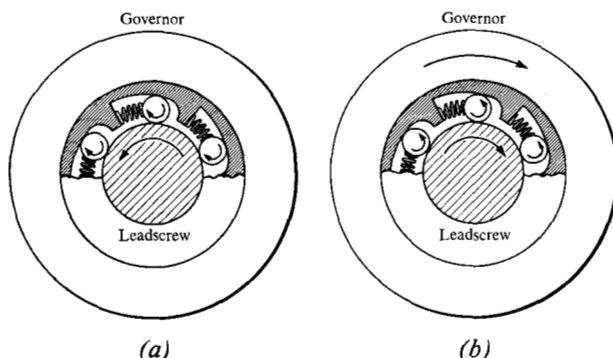


Figure 2 Schematic representation of rebound governor: (a) leadscrew rotating in the escapement direction with clutch slipping, or "overrunning"; (b) leadscrew rebounding with clutch locked and governor coupled.

Solution adopted

The simplicity of the idea of coupling an inertia through a clutch to the escapement system was the main factor in making this choice. Theoretically, the device could be mounted on any one of a number of shafts in the system where space was available and in which the governor could be easily serviced. The main effect on the system was the addition of a light drag during escapement. No external mechanism was required to engage the clutch, nor to disengage it during backspacing, since the entire governor assembly could rotate in reverse direction.

Development consisted mainly of establishing the best location and the proper inertia of the governor and the reliability of the clutch. Factors important to the location were clutch backlash, i.e., the amount of rebound motion required to actuate the clutch, the governor inertia, and the clutch drag torque. Since the governor could not dissipate energy instantaneously, the clutch backlash had to be less than the allowable pinwheel rebound, or else the clutch had to be mounted where the pinwheel motion is multiplied. The leadscrew was the logical place, since, in the large pitch, pinwheel motion is multiplied five times. Location on the leadscrew was advantageous from the standpoint of inertia, also. During rebound, the governor "sees" the effective inertia of the escapement system—the smaller the system inertia, the smaller the governor inertia required. The leadscrew is the highest velocity shaft and therefore is the one where the effective inertia is lowest.

For a given drag torque, the best location would be on the shaft which has the least rotation, since less energy would be lost, or the least amount of torque would be subtracted from the input. The pinwheel shaft would be the best location from this standpoint.

Of these factors, it was felt that the clutch backlash would be least controllable and most likely to change with time. For this reason the leadscrew location was chosen, since it minimizes the effect of backlash. The higher energy loss due to drag could be overcome.

Analysis

The amount of governor inertia needed to limit the rebound was determined analytically and verified on the machine. Only an approximate solution is presented here. However, the reader who finds momentum and energy relationships intriguing will see in this a variation of the classical problem of coupling two masses. Simply stated, the situation is as follows: A mass (the escapement system) pushed by a constant force, contacts a relatively stiff spring; the mass reverses its direction of travel, and at some time during the reverse travel is coupled to a second mass (the rebound governor), initially stationary. The coupling is momentary. The problem, then, is to determine how large the second mass must be to limit the displacement of the first mass to a given amount.

The solution is well suited to the analog computer; however, a relatively simple solution (in this case sufficiently accurate) can be found by energy relationships. The energy which the system and the governor must absorb can be determined by measuring the system rebound angle with the governor removed, and multiplying the angle by the torque which retards the system. With the governor acting, this energy is absorbed by both the governor and the system. The energy portion taken by the governor is a function of the governor inertia; the remainder, taken by the system, determines how far the system will rebound. In equation form, the energy returned to the system without the governor is

$$E = T\theta_R, \quad (1)$$

where T is the retarding torque and θ_R is the rebound angle of the system when the governor is removed. With the governor attached, this same energy will bring the governor and system up to a common velocity, ω

$$E = \frac{1}{2}(I_G + I_S)\omega^2, \quad (2)$$

where I_G and I_S are the moments of inertia of the governor and the system. With small backlash, this velocity will be reached approximately as the system separates from the "fixed" stop. Combining Eqs. (1) and (2), and solving for the common velocity,

$$\omega^2 = \frac{2T\theta_R}{I_G + I_S}. \quad (3)$$

After reaching the common velocity, the governor and system separate. The kinetic energy in the system is dissipated by turning through the allowable rebound angle θ_{RG} , so that

$$\frac{1}{2} I_S \omega^2 = T\theta_{RG}. \quad (4)$$

Substituting (3) into (4) and solving for I_G ,

$$I_G = I_S \left(\frac{\theta_R}{\theta_{RG}} - 1 \right). \quad (5)$$

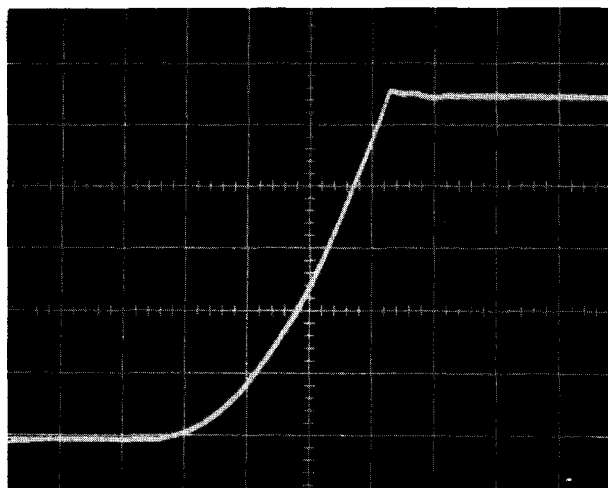


Figure 3 Pinwheel displacement vs. time, with rebound governor.

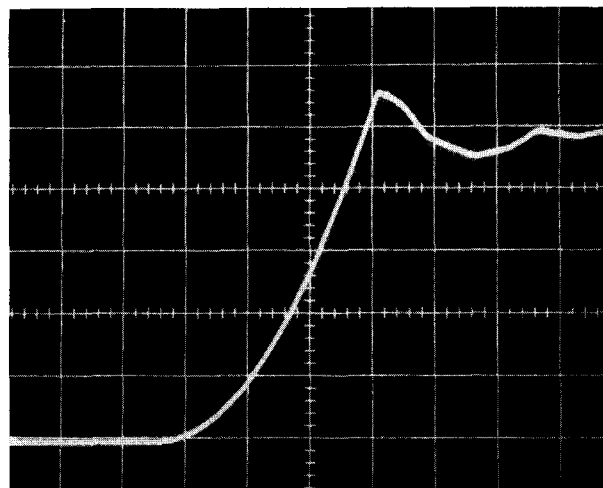


Figure 4 Pinwheel displacement vs. time, without rebound governor.

Thus, the governor moment of inertia can be determined by measuring or estimating the rebound angle θ_R which the system has without the governor, knowing the allowable rebound angle θ_{RG} when the governor is used, and knowing the system moment of inertia, I_S . Although the equation was developed on the assumption that the clutch backlash angle was small, there is a certain amount of built-in compensation. With backlash, the angle through which the system turns after a common velocity is reached must be made smaller to maintain the total allowable rebound angle. At first glance, this would seem to require increased governor inertia. However, the presence of backlash brings about an impact between the governor and the system which dissipates energy not accounted for in the equation and reduces the governor inertia required. Consequently, the two effects tend to cancel.

The development of a suitable clutch concentrated on meeting the requirements of low backlash and low drag torque without sacrificing consistent, reliable performance. First efforts were directed toward spring clutches. The clutch finally selected was a roller clutch of special design, now commercially available, which gave lower drag and backlash than the spring clutches used. Testing has proven its reliability in this application.

The use of the roller clutch emphasized the need for a brake to dissipate the energy received by the governor. Previously the clutch friction was sufficient to stop the governor rotation before the next cycle occurred, but the roller clutch transferred more energy to the governor and has less friction to slow it down. As a result, in high speed operation, the governor would reach such a high velocity in the rebound

direction that it would lose its effectiveness to limit rebound. The brake adds enough drag to insure the governor's stopping between cycles. (As an aside, it is interesting to note that the effectiveness of the governor can be increased by rotating it in the escapement direction while escapement occurs. It was not necessary to do so in this case.)

Results

The oscilloscope traces of pinwheel displacement versus time, Figs. 3 and 4, sum up the effect of the rebound governor on the escapement system. Figure 3 shows the displacement with the governor operating; Fig. 4 shows it with the governor removed from the machine. At the left in Fig. 3, the pinwheel is stationary; it begins moving as indicated by the upward slope of the trace, travels through the escapement angle, impacts the stop, and settles. Figure 4 shows a failure caused by excessive rebound; the pinwheel has backed up and stopped on a pin other than the pin set for the desired escapement. The traces also show the relative amount of drag introduced by the governor. The escapement time in Fig. 3 is slightly longer than that in Fig. 4.

Acknowledgments

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