Governors for Dials

W. PFERD *Station Apparatus Development*

As a telephone dial "runs down" from its wound-up position, the dial mechanism generates pulses which operate relays at the telephone central office. To compensate for pulse distortion during transmission over the telephone line, the dial pulses must be closely controlled in frequency and form. Thanks in part to a new type of governor, which provides improved pulse control, accurate dialing is obtainable over the considerably longer transmission loops permitted by the 500-type telephone set.

One billion times a day throughout the Bell System, a little mechanism, about the size of a bottle cap, swings into action. It is the governor, the heart of your telephone dial, regulating and restraining, to control the run-down speed of the moving parts. Why regulate and restrain? During run-down the dial mechanism produces from one to ten interruptions in the line current by the opening and closing of a pair of contacts. In turn the pulses created in the line give directions to central office switching apparatus which then completes the call. By controlling the run-down speed the governor keeps the pulses uniform. The governor and pulsing arrangement for the new 7-type dial mechanism used in the 500-type telephone set are shown schematically in Figure 1.

If the pulses reaching the central office were exactly like those generated by the dial, the designers of dials and central office apparatus and circuits would find themselves far less restricted. Unfortunately the dial pulses are distorted by the electrical characteristics of the customer's loop. To compensate for this distortion and insure accurate registration of the pulses at the central office, the dial and central office equipment must be designed to operate to close limits of performance. The designs must also be such that there is negligible change of adjustment due to use, time, or weather conditions, which might affect the ability to accurately send or receive dial pulses. The near-perfect performance of dial telephone systems is due in no small measure to the dependable job of the governor in closely controlling the run-down speed of the dial so that the pulses delivered at the central office are of acceptable frequency and form.

The need for speed control was recognized in a signaling transmitter patented in 1894 where "in order that the motion may be regular and not too rapid, the train has attached to its remote member a fan necessary to obtain the desired speed of rota-

In the photograph at the head of the page H. J. Hershey attaches specimen material to friction tester. Test results reveal a material's coefficient of friction and resistance to wear — important factors in the operation of governors.

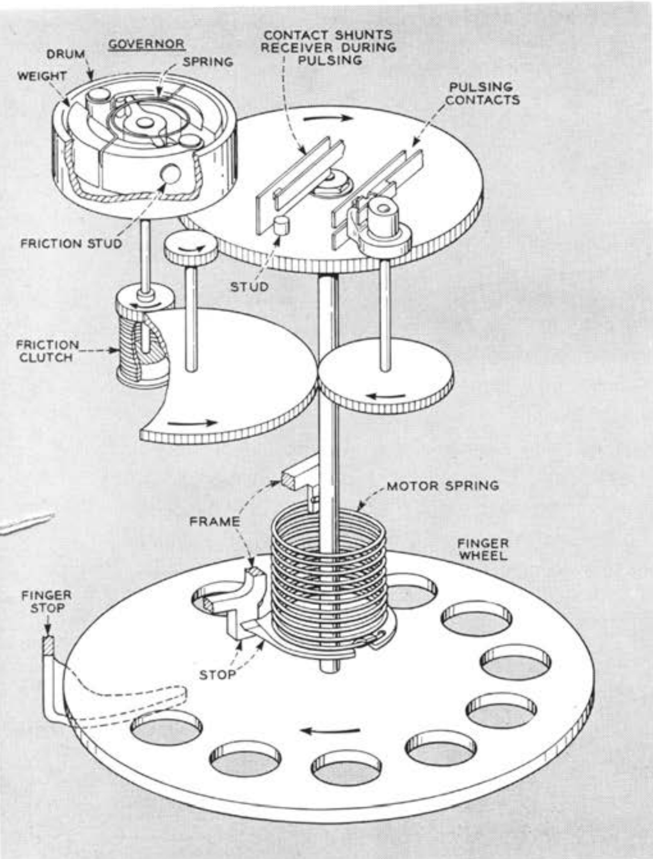

Fig. 1 — Simplified diagram of 7-type dial mechanism; governor appears top left.

tion." In 1897, another patentee described the regulation of his device by stating, "I employ the atmospheric dash-pot to control the movements of the spring contact fingers which otherwise might be too rapid." This was in turn followed in 1898 by a device having "parts returned to the normal position, limited by an escapement mechanism to a moderate rate of speed." As indicated, the necessity for speed regulation was well recognized in these early devices, but the mechanisms employed for this purpose were soon found to have undesirable manufacturing and operating limitations.

Better control of speed was soon made available by the application of centrifugal-friction governors for controlling customer pulse-sending equipment. The first centrifugal-friction governor appeared in pulsing apparatus in 1906, and was used in the first Bell System dial patented in 1915. The speed controller used in the 5-type dial, standard for about the past fifteen years, Figure 2, is also a centrifugal-friction governor. Speed controllers of this type generally involve two arms which constitute a "fly-bar." At the extreme ends there are pivoted weights which are so moved by centrifugal force during rotation that friction studs are brought into contact with a stationary surface, resulting in friction that retards rotation.

A continuing part of dial development has been the provision of mechanisms capable of producing pulses timed sufficiently to insure service over ever-longer telephone lines or over smaller gauge cables. Since the degree of timing is primarily dependent on the action of the governor, it was recognized that a general theoretical analysis for governors would help in pointing the way to improved designs. The late C. R. Moore investigated this problem in the thirties, and derived from theoretical considerations, general equations of motion relating to governors. The relationships derived by the Moore analysis are extremely useful in that they can be used to indicate the influence of various design factors on the performance of a governor.

In deriving the general equations of motion for a governor, two assumptions are made concerning the action. During the interval of time that the governor is approaching the critical velocity, ω_o, when contact of the friction surfaces first occurs, the motion is assumed to be that of a simple fly-wheel, constantly accelerating. The angular velocity of the governor during the time from rest to the critical velocity, ω_o, is then given by

$$\omega = \frac{Gt'}{I} \qquad (1)$$

where G equals applied torque, t′ equals time from start of motion, and I equals moment of inertia of the governor assembly about the shaft.

After stud-to-drum contact occurs, it is assumed that there is no further pivoting of the weights or the fly-bar, and the assembly rotates as a rigid body. During this time the general equation of motion is in the form

$$\frac{d\omega}{dt} + g\omega^2 = h$$

which can be solved for the angular velocity, ω, to give

$$\omega = q \tanh\left(\frac{ht}{q} + ln\sqrt{A}\right) \qquad (2)$$

where q equals regulated or terminal angular velocity, t equals time measured from moment of braking, h equals design constant, and A equals design and adjustment constant.

This theory was applied in developing the governor used in the 7-type dial* for the 500-type telephone set† and has resulted in an improved governor which controls the return speed of the mechanism more accurately than in any previous Bell System station dial.

Figure 3 shows a plot of these equations of motion for the new drive-bar type governor used in the 7-type dial. The curves show the theoretical angular velocity of the governor at any time from the moment of release. As indicated, the pulse train is designed to start well after the critical speed has been reached. This avoids the objectionably long pulse which would be formed while the governor is gathering speed.

As shown in Figure 4, the weights of the new governor are free to pivot at the ends of the fly-bar which, in turn, is allowed to rotate with respect to the shaft. Rotation is imparted to the system by the drive-bar which presses against each weight at a specific point. As the mechanism begins to rotate during dial run-down, the two weights are caused by centrifugal force to move outward against the tension of a spring. Movement of the weights about their pivots continues until the friction studs touch the drum. At this instant governing begins, and controls the dial speed until the end of the run-down. The speed attained by the governor will be dependent on the friction between the studs and drum, the magnitude of the driving torque, and the tension to which the spring of the governor has been adjusted.

Since dials are used throughout the telephone plant, it is necessary that they be capable of maintaining the required rundown speed under the wide variety of service conditions encountered. The governor depends on stud friction in controlling the speed, and therefore changes in the coefficient of friction between the stud and drum will affect the degree of speed control. Also, the governor must be able to respond to and compensate for changes in the applied torque. Because of the different service conditions encountered, friction and torque vary from dial to dial and over the life of a dial. For best dial pulse regulation, changes in the value of these factors should have a minimum effect on governor speed.

Each station dial is adjusted initially for speed

* Record, *May*, 1952, *page* 211. † Record, *September*, 1951, *page* 414.

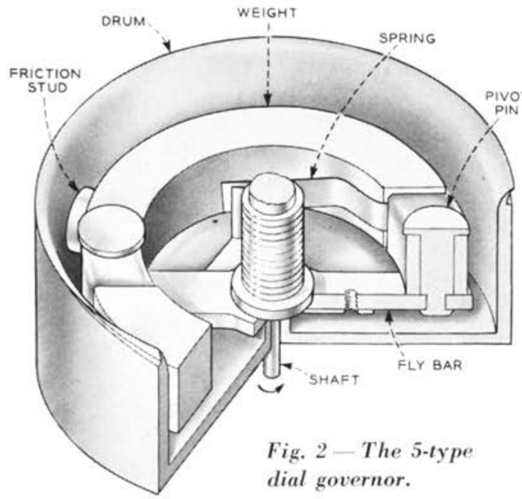

Fig. 2 — The 5-type dial governor.

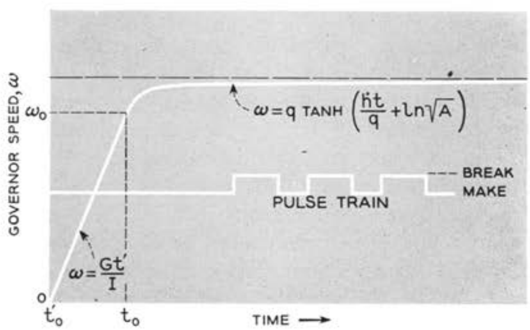

Fig. 3 — Equations for motion of 7-type governor.

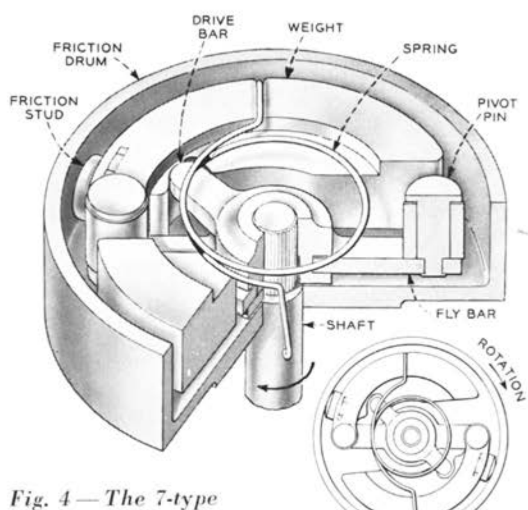

Fig. 4 — The 7-type dial governor.

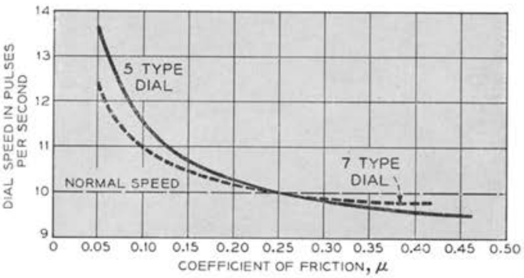

Fig. 5 — Pulsing rate versus coefficient of stud-to-drum friction.

so that the contact springs will function at 10 ±0.5 pulses per second, a rate suitable for system-wide application. At the time this speed adjustment is made, a particular friction condition exists between the governor studs and drum. At any subsequent time, there is always the possibility of a change occurring in this friction value. Such factors as very high humidity, lubrication products traveling to the stud operating region, or the accumulation of foreign material or wear particles, may produce different values of friction, and hence, result in variations in governor and dial speed from the initially adjusted value. The change in pulsing rate for the 7-type and 5-type dials resulting from changes in stud-to-drum friction in the governors is shown in Figure 5. Improved speed control is indicated for the 7-type dial for all values of friction. This has been brought about in part by operating the new governor at increased terminal speed which results in a higher centrifugal force.

The initial speed adjustment of the governor is also dependent on the driving torque which in turn depends on the efficiency of the dial mechanism at the time of adjustment. Subsequently, this torque will vary as the friction within the dial mechanism varies. Initially, the mechanism is lubricated and the moving members operate smoothly. During the early life of the mechanism, the running-in process may result in an increase in efficiency and a corresponding increase in torque on the governor. Over a long period of time, however, the accumulation of dirt and wear products may affect the mechanism so that more torque is needed to drive the moving parts. This results in a decrease in the torque going to the governor. Fluctuations in torque must be sufficiently compensated for by the governor to maintain proper speed of the dial.

The governor must also be capable of maintaining adequate speed when subjected to gross changes in torque, such as that induced by the customer when forcing the fingerwheel to shorten dialing time. This habit of some customers can completely dissipate the benefits derived from normal speed regulation and cause faulty detection of the number dialed. To forestall this arbitrary shortening of the pulse, and the possibility of wrong numbers, the governor should be capable of limiting the forced rundown of the dial to a reasonable speed. The effect of changes in governor input torque on pulsing rate for the 7-type and 5-type governors is shown in detail in Figure 7.

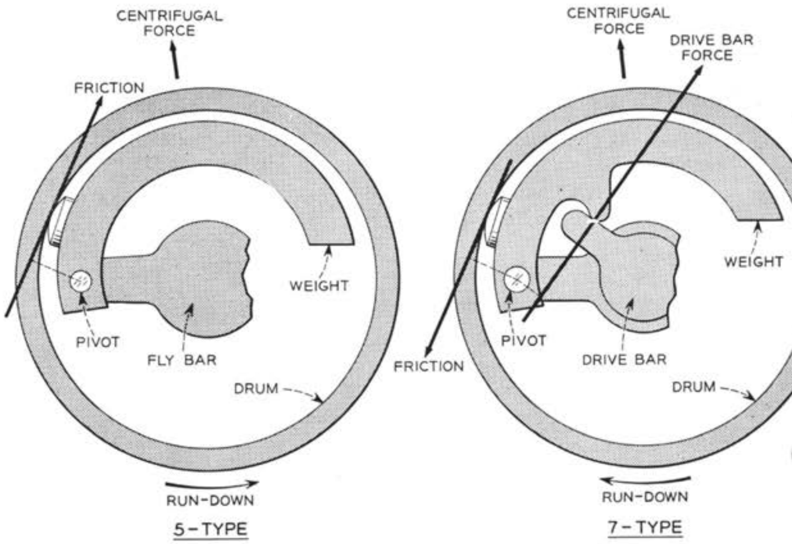

Fig. 6 — As pivoted weight rotates centrifugal force presses the stud against the drum. Depending on the direction of rotation the centrifugal force is aided or opposed by the torque produced by the stud-to-drum friction about the pivot. In the 5-type governor, this torque opposes the centrifugal force, hence reduces braking action. In the 7-type it aids the centrifugal force, and thus strengthens the braking which is further assisted by the torque produced by the pressure of the drive bar on the weight.

The marked improvement in ability to compensate for changes in input torque achieved for the new drive-bar governor over the 5-type governor results primarily from two considerations. First in the 7-type governor, the mechanism rotates opposite in direction to that of the 5-type governor. As illustrated in Figure 6 this causes the braking action to assist centrifugal force in keeping the friction studs against the drum. Second, the centrifugal force is aided still further by the driving force transmitted to the assembly by the drive bar. This force produces a component acting about the weight pivot in the same general direction as the centrifugal force which also helps increase the braking action. Although the governor and other dial parts are designed to have substantial margins for reliable performance under heavy or abnormal usage, long continued or excessive forcing will almost certainly result in rapid wear or breakage.

At the present time there are more than 30,000,000 dials in use throughout the Bell System. Current production for new installations and replacement is almost 4,000,000 dials per year. For production of this magnitude, design of apparatus easily suited for mass manufacture at low cost is obviously required. Through close cooperation with engineers of the Western Electric Company, this has been achieved to a very satisfactory extent for the new governor. For example, the problem of close dimensional tolerances required for proper action of the drive bar and weights was solved by manufacturing the parts of sintered powdered metal. This method of manufacture, semi-automatic assembly and machining of the friction studs, and simplified holding of the governor assembly on the shaft have all contributed to enable the new design to be produced at favorable cost.

Experience with the drive-bar governor in 7-type dials shows that the performance of these dials under service conditions represents a material improvement over earlier designs. The response of the dial to changes in friction between the governor stud and drum is well within the design objective and the compensation by the governor for changes in applied torque is fully realized. Because of the degree of speed control exercised by the drive-bar governor, dialing over the longer telephone lines permitted by the 500-type telephone set is satisfactorily achieved.

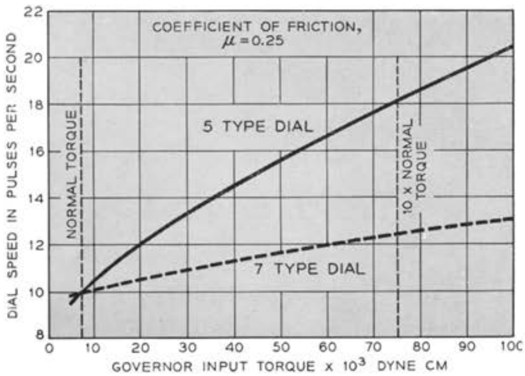

Fig. 7 — Pulsing rate versus input torque.

THE AUTHOR

After serving three years in the Army Air Corps, WILLIAM PFERD attended Rutgers University, receiving the B.S. degree in M.E. in 1947. He joined the Laboratories that year, later continuing his studies to receive an M.S. degree in M.E. from Newark College of Engineering in 1951 His time at the Laboratories has been devoted to the design and development of the station ringer for the 500-type telephone set and, more recently, the dial mechanism for the same set. At present he is concerned with new coin collector development.