A New Concept for a Capstan Drive System for Professional and Home Tape Recorders*

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A new drive system for tape recorders is described. The heart of the system consists of an electronically controlled asynchronous high-slip eddy-current motor. The completely homogenous rotor delivers a highly uniform torque. The capstan shaft can be coupled to the rotor directly, without requiring mechanical isolation such as a flexible coupling driving a flywheel. Speed ratios of 1:16 are possible. The paper gives a description of the electronic control circuit.

INTRODUCTION One of the prime requirements for top performance of audio tape recorders is the uniformity of tape movement. Basically, long- and short-term stability have to be considered separately, since different aspects of the motor or drive systems are responsible for each.

In order to avoid changes of the pitch of the recorded material, an absolute long-term speed accuracy of ±0.2% is generally accepted as adequate. The alternating components of speed variations (periodic and non-periodic) are called flutter and wow. Specifications often require flutter and wow values better than 0.1% rms at 7.5 ips (19 cm/s) tape speed.

Today the hysteresis synchronous motor is in common use as a capstan motor for high-quality tape recorders. Unfortunately this type of motor presents certain problems:

1. The motor speed is directly proportional to the powerline frequency. This dependence is a real problem in all cases where the powerline frequency is not stable.

2. At synchronous speed the mechanical phase depends on the load torque. Mathematically, the motor is described by a second-order linear differential equation: it is a "resonant circuit". In response to a load variation, the rotor produces damped speed oscillations, often called "hunting". The amount of flywheel inertia is limited, otherwise the motor may become unstable. When other equipment is switched on and off the powerline, transient voltage changes occur. These cause the mechanical phase angle of the motor to change, producing flutter.

3. Periodic flutter is caused by the poles of the motor. Sometimes a flexible coupling (or belt drive) is required, together with an additional flywheel. (This is more common with European recorders than with those built in the USA.)

4. Efficiency is low (below 10%) and weight is great for the mechanical power delivered.

The hysteresis synchronous motor has two advantages: 1. There are no parts exposed to wear; and 2. There is no radiation of radio-frequency interference.

Design studies aimed at producing a constant-speed capstan motor avoiding all the mentioned disadvantages of the hysteresis synchronous motor have led to the development of a servo-controlled drive system featuring a high-slip eddy-current asynchronous motor.

EDDY CURRENT MOTOR

This motor consists of a conventional multiphase sta-

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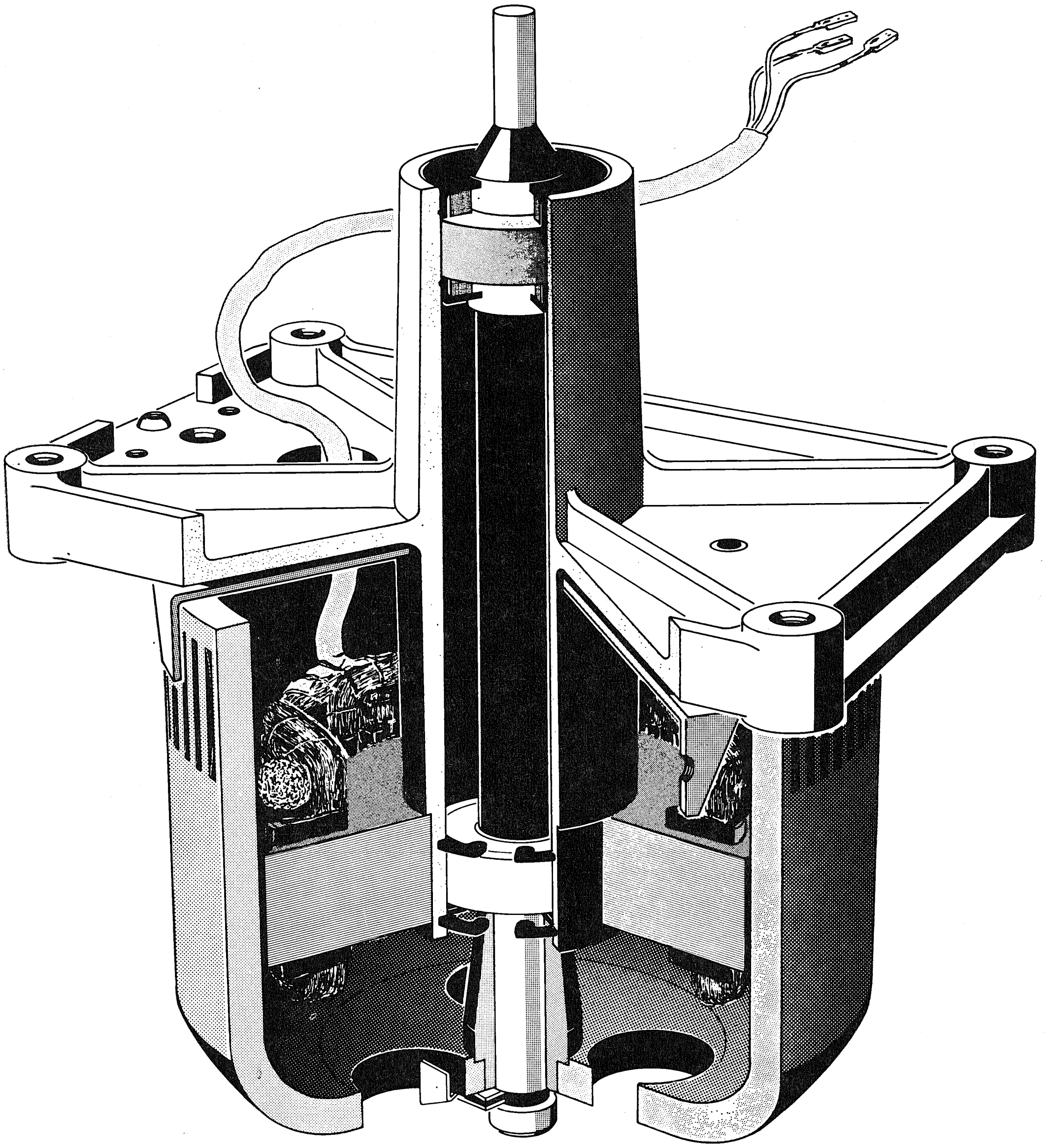


Fig. 1. Cutaway view of the motor.

tor generating a circular rotating field. The rotor itself acts as an eddy-current conductor as well as a flux return path. It is made of pure, magnetically soft iron. Torque pulsations, and therefore speed variations, are kept to an absolute minimum because the rotor is of completely homogenous design, without gaps for conductors. It is possible to attach the capstan directly to the rotor without a flexible coupling between them. No additional flywheel is required if an "outer rotor" design is chosen. Fig. 1 gives a cut-away view of this motor. Fig. 2 shows that the speed of this high-slip motor is quite dependent on the load torque (when operated at constant motor voltage), and on the motor voltage (when operated at constant torque). Design studies proved the feasibility of speed regulation by changing the motor voltage; this is much simpler than the alternative of varying the supply frequency, which would require a bulky motor drive amplifier. It turned out to be quite easy to change the input voltage to the motor by inserting a single power transistor (connected through a bridge rectifier) in series with the power line (Fig. 3).

SERVO ACTION

The actual motor speed is measured by a gear-wheel tachometer. A high-precision gear of 120 teeth is cut into the rotor periphery. The teeth vary the magnetic flux in a pickup coil. The frequency is thus proportional to the speed.

An electronic circuit measures the instantaneous frequency value and corrects any deviation from the desired frequency by variation of the motor supply voltage. The resonant frequency of an LC circuit acts as the speed reference.

Figure 4 shows a schematic of the complete capstan servo system. The circuitry can be divided into three main parts: the tachometer amplifier and limiter; the discriminator; and the dc amplifier with power controlling stage.

The tachometer amplifier also acts as a limiter. All amplitude modulation of the tachometer signal is removed and a clean symmetrical squarewave signal is delivered to the discriminator. The amplitude of this

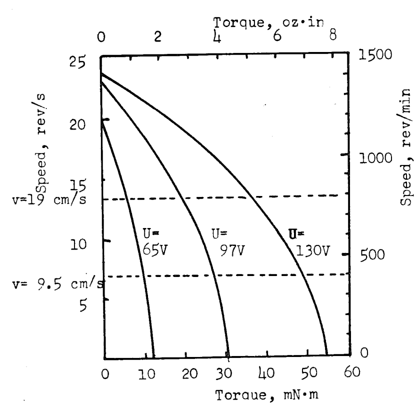


Fig. 2. Motor speed vs load torque. Parameter: **U**, motor input voltage. Operating rotational speeds for tape speeds **v** = 7.5 ips (19 cm/sec and v = 3.75 ips (9.5 cm/s) are also shown.

signal is determined by the saturation voltage of the transistor stages and the dc supply voltage (22 V). A dc coupling adjusts the operating points of the amplifier stages for best symmetry of the squarewave signal.

The discriminator is actually an LC-slope detector which acts against a reference derived from the signal itself. Thus variations of the dc supply voltage E_b causing variations of the driving squarewave signal will have only a small effect on the output signal of the discriminator. No special stabilization of the dc supply voltage is required. Speed adjustments are achieved by changing the resonant frequency of the LC circuit. The schematic shows two speeds; the second (lower) speed is trimmed by a small series resistance which decreases the Q of the resonant circuit.

The voltage *vs* frequency characteristic of the discriminator, shown in Fig. 5, is similar to that of the well-known ratio detector encountered in most FM tuners. The range of the following dc amplifier is limited: as long as the discriminator delivers a signal below 0.7 V, the motor gets full supply voltage; when the signal rises above 0.8 V, the regulating series transistor is cut off.

TEMPERATURE STABILIZATION

The temperature coefficients of the inductance and the capacitance of the discriminator must be matched in order to gain independence from the ambient temperature. It is easily possible to make the temperature coefficients track each other over the range from −15°C to +65°C; over this range the angular speed of the motor is held to within ±0.2%. Figure 6 shows some typical curves.

The following dc amplifier is of traditional design. The ac components in the servo signal are removed by two RC filters. In addition, a lag network is provided which reduces the bandwidth of the closed-loop system as much as is necessary to prevent the residual eccentricity of the tachometer gear from causing periodic speed variations. In addition, this network improves the stability margin of the system and allows higher static gain.

SERVO ANALYSIS

A closer look at block diagram of the servo system shows a first-order cubic system. Basically, the system is

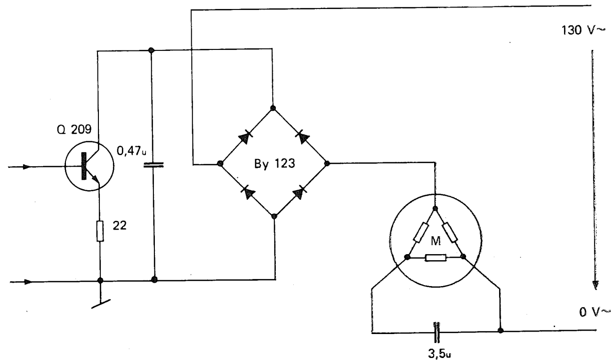


Fig. 3. Schematic of the power stage.

of first order because the discriminator delivers a signal proportional to the motor speed. The system can be classified as a velocity servo.

The non-linearity is caused by two things:

1. The motor generates a torque proportional to the square of the applied input voltage: $T = K \times Eac^2$.

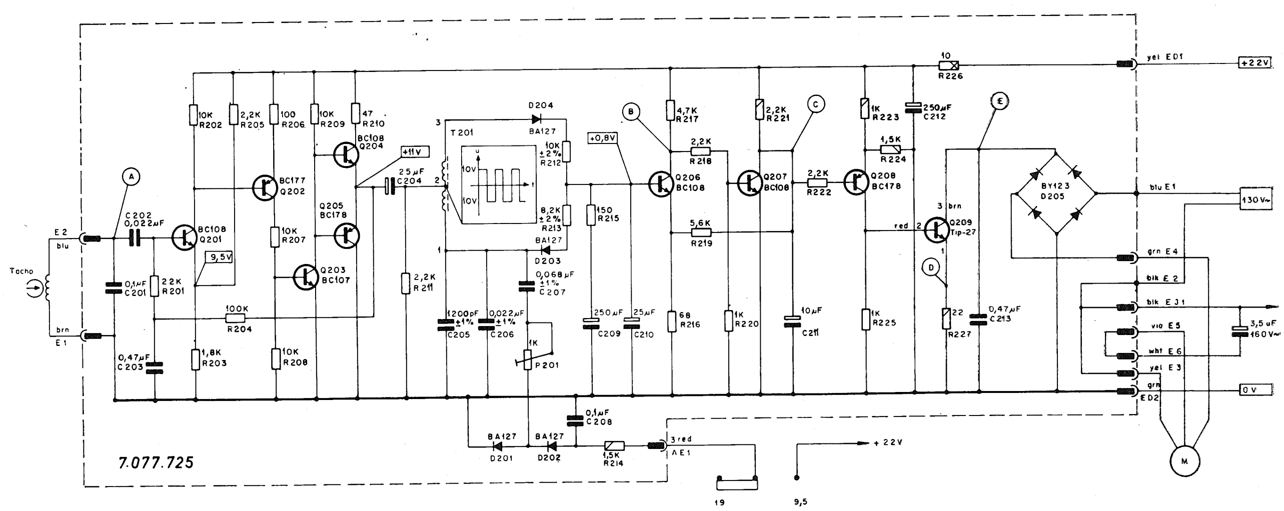


Fig. 4. Schematic of the entire circuit.

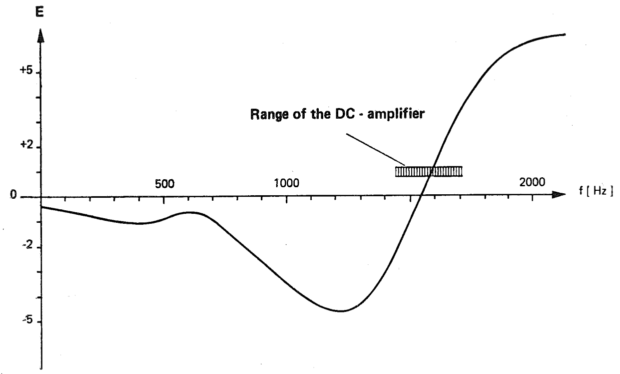


Fig. 5. Voltage vs frequency characteristic of the discriminator.

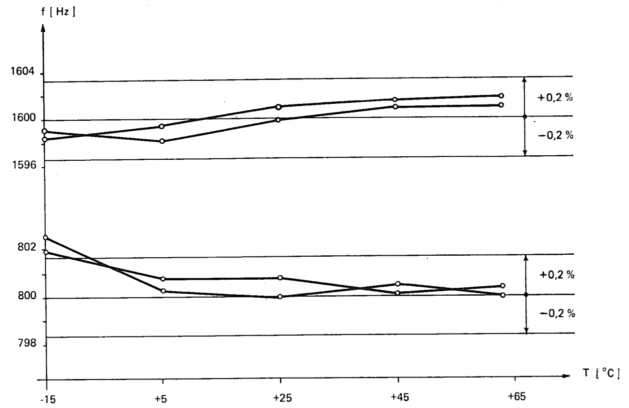


Fig. 6. Speed vs temperature curves for the system as a whole.

2. The generated torque decreases with rising speed. A linear approximation of this behavior is possible (see Fig. 2.). Both effects together lead to a cubic system which, for a mathematical analysis, is conveniently replaced by a linear approximation.

SYSTEM PERFORMANCE

Some of the characteristics of the system operating at a tape speed of 7.5 ips (19 cm/s) are shown below.

Table I. Drive system specifications.

Tape Speed	7.5 ips (19 cm/s)
Tachometer frequency	1600 Hz
Starting torque of the motor	7.6 inch-ounces (55 mN·m)
Supply voltage	130 V ac, 50 or 60 Hz
Torque required with tape moving at 7.5 ips	1 inch-ounce (7.5 mN·m)
Motor voltage	70 V ac
Power consumption	7 to 13 W

The steepness of the discriminator and the gain of the following amplifier cause the motor voltage to go from 0 V ac to 120 V ac for a 3 Hz frequency deviation at a tachometer frequency of 1600 Hz. A load variation from no load to full permissible load will cause the average speed to change less than 0.1%.

Line voltage fluctuations of ±20% cause changes in the motor speed of about ±0.05%.

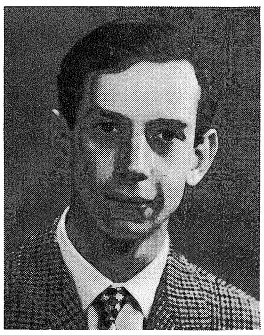
Operating dc supply voltage fluctuations of E_b = 22 V ±10% cause errors in motor speed of 0.1%.

Changing the powerline frequency from 50 to 60 Hz causes an error in speed of less than 0.05%.

Typical flutter and wow values (for recording, rewinding and reproducing) at 7.5 ips are: ±0.05% weighted quasi-peak per DIN 45-507; ±0.12% unweighted quasi-peak; 0.04% rms per USAS Z57.1—1954.

At 3.75 ips (9.5 cm/sec) the tachometer frequency is 800 Hz, and the other values are about 1.5 times those measured at the higher speed.

THE AUTHOR



Arturo E. Stosberg received his Dipl. Ing. in electrical engineering in 1957 from the Swiss Institute of Technology at Zurich.

The next two years were spent in post-graduate work at the Institute as an assistant at the Institute for Automatic Control under Professor E. Gerecke.

The following two years Mr. Stosberg was a research and development engineer with a Swiss company which specialized in control electronics for the textile industry.

In 1962, he came to the United States and joined Machtronics Inc. (MVR-Corp) at Palo Alto, California where he became involved in the development of helical video tape recorders. Mr. Stosberg returned to Europe in 1965 to join the engineering staff of the Willi Studer Company at Regensdorf, Switzerland where he has contributed to developments (mostly servo control) in the tape recorder field.

He is a member of the Audio Engineering Society.