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A NEW CONCEPT OF A CAPSTAN DRIVE SYSTEM FOR PROFESSIONAL AND HOME TAPE RECORDERS

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A NEW CONCEPT OF A CAPSTAN DRIVE SYSTEM FOR PROFESSIONAL AND HOME TAPE RECORDERS

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SUMMARY The paper deals with a new drive system for different tape recorders. The heart of the system consists of an electronically controlled asynchronous high slip eddy current motor. The complete homogenous rotor delivers a highly uniform torque. The capstan shaft can be coupled to the rotor directly without mechanical damping by a flexible coupling with flyweel. Speed ratios of 1:16 are possible. The paper gives a description of an electronic control circuit and an analysis of the servo system.

Introduction :

One of the prime requirements for top performance of audio tape recorders is the uniformity of tape movement. Basically the long and short term stability have to be considered separately. 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 accurancy of ± 0.2 % is generally accepted to be adequate. The periodic and non periodic alternating components of speed variations are called flutter and wow. Specifications often ask for flutter and wow values better than 0.1 % (RMS) at 7.5 ips tape speed.

Today the hysteresis synchronous motor is in extended use as a capstan motor for high quality tape recorders. Unfortunately this motor type shows some often negative specialities which are listed below :

1. The motor speed is directly proportional to the power line frequency. This dependence has to be considered to be an important disadvantage in all cases where the power line frequency is not stable.

2. At synchronous speed the generated torque depends on a phase angle difference. Mathematically the motor is described by a second order system. In responce to a load variation the rotor shows a tendency of damped speed oscillations. (often called hunting) The amount of flywheel inertia is limited, otherwise the motor gets unstable. Speed disturbances are also generated by minute parasitic switching transients on the power line.

3. Periodic flutter caused by the poles of the motor. Often a flexible coupling (or belt drive) is required together with an additional flywheel.

4. Low efficiency (below 10 %) and heavy weight in reference to the delivered mechanical power.

5. No parts exposed to wear.

6. No radiation of radio frequency interferences.

The last two points have to be scored as advantages.

Design studies aimed at producing a constant speed capstan motor avoiding all the mentioned disadvantages of the mentioned hysteresis synchronous motor 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 stator generating a circular rotating field. The rotor itself acts as an eddy current conductor as well as a flux return path. It is made out of pure magnetically soft iron. Torque pulsations and therefore speed variations are kept to an absolute minimum as the rotor is of completely homogenous design without gaps for special conductors. It is possible to mount the capstan mounted directly to the rotor without flexible coupling. No additional flywheel is required if an outer rotor design is chosen. Fig. 1 gives a crossection of this motor type. The speed - torque - caracteristics of this high slip motor show a considerable load dependence of the rotational speed (Fig. 2). Design studies proved the feasability of a speed regulation by changing the motor voltage instead of varying the supply frequency which would require a bulky motor drive amplifier. It turned out to be quite easy to change the drive voltage of the motor by inserting a bridge rectifier loaded by a single power transistor. (Fig. 3)

Servo Action :

The actual motor speed is measured by a tone generator. A high precision gear of 120 teeth is cut into the rotor periphery. The teeth vary the magnetic flux in a pick up coil. The speed is thus transferred into a proportional frequency.

An electronic circuit analyses the momentary value and corrects any deviation from the desired frequency by variation of the motor supply voltage. As the speed reference acts the resonnance frequency of LC-circuit.

Fig. 4 shows a schematic diagram of the complete capstan servo system. The circuitry can be devided into three main parts, namely

1. The tachometer amplifier and limiter
2. The discriminator
3. The DC - amplifier with power stage

The tachometer amplifier acts as a limiter. All amplitude modulations of the tachometric signal are removed and a clean symmetrical square wave signal is delivered to the discriminator. The amplitude of this signal is determined by the saturation voltage of the transistor stages and the DC - supply voltage (22 V). DC - coupling adjusts the operating points of the amplifier stages for best symmetry of the square wave signal.

The discriminator is actually a 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 square wave signal will have only little 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 resonnance frequency of the LC - circuit. On this schematic diagram two speeds are provided, the second and lower speed is trimmed by a small series resistance which decreases the figure of merit of the resonnance circuit.

The caracteristic of the discriminator (voltage versus frequency) is to a certain degree similar to the well known ratio detector encountered in most fm - tuners. Fig. 5 shows this plot. The range of the following DC - amplifier is marked. As long as the discriminator delivers as signal below 0.7 volt the motor gets full supply voltage. When the signal raises above 0.8 volt the regulating series transistor is cut off.

Temperature Stabilization :

The temperature coefficients of the inductance and the capacitance of the discriminator have to be matched in order to gain independence of the ambient temperature. Tracking ranges from – 15 °C to + 65 °C in which the final motor angular speed is held within ± 0.2 % are easily possible. Fig. 6 shows some typical curves.

The following DC - amplifier is of traditional design. AC - components in the servo signal are removed by two RC - filters. In addition a lag network is provided. It reduces the bandwidth of the closed loop system to the necessary degree 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 to the servo system block diagramm shows a cubic system of first order. Basically the system is of first order as 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 reasons :

1. The motor generates a torque proportional to the square of the applied AC - voltage. $T = K \times E^2_{ac}$
2. The generated torque decreases with raising speed. A linear approximation of this behaviour is possible. Fig. 2.

Both effects together lead to a cubic system which for a mathematical analysis have to replaced by a linear approximation.

Some Intersting Points on the System :

1. Tape speed : 7.5 ips tach frequency : 1.6 kHz
   3 3/4 ips 800 Hz

   Starting torque of the motor : 550 cmp equals to 7.6 inch-ounces
   Supply voltage : 130 V_{ac} 50 or 60 Hz
   Required torque at 7.5 ips with moving tape : 1 inch-ounce
   equivalent to 75 cmp
   Motor voltage : 70 V_{ac}
   Power consumption : 7 to 13 watts

2. The steepness of the discriminator together with the gain of the following amplifier causes a passage of the motor voltage from $0V_{ac}$ to 120 V_{ac} within 3 Hz frequency deviation at 1.6 kHz tachometer signal frequency. The system will react to a load variation from no load to full permissible load by a static speed variation of less than 0,1 %.

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

4. Operating voltage fluctuations of E_b = 22 V ± 10 % cause faults in motor speed of 0.1 %.

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

6. Typical flutter and wow values :
   7.5 ips : 0.05 % peak to peak weighted according to DIN-standards
   0.12 % peak to peak linear
   0.04 % American standards (nearly unmeasurable)
   The figures at 3 3/4 ips are about 1.5 times those measured at the higher speed.

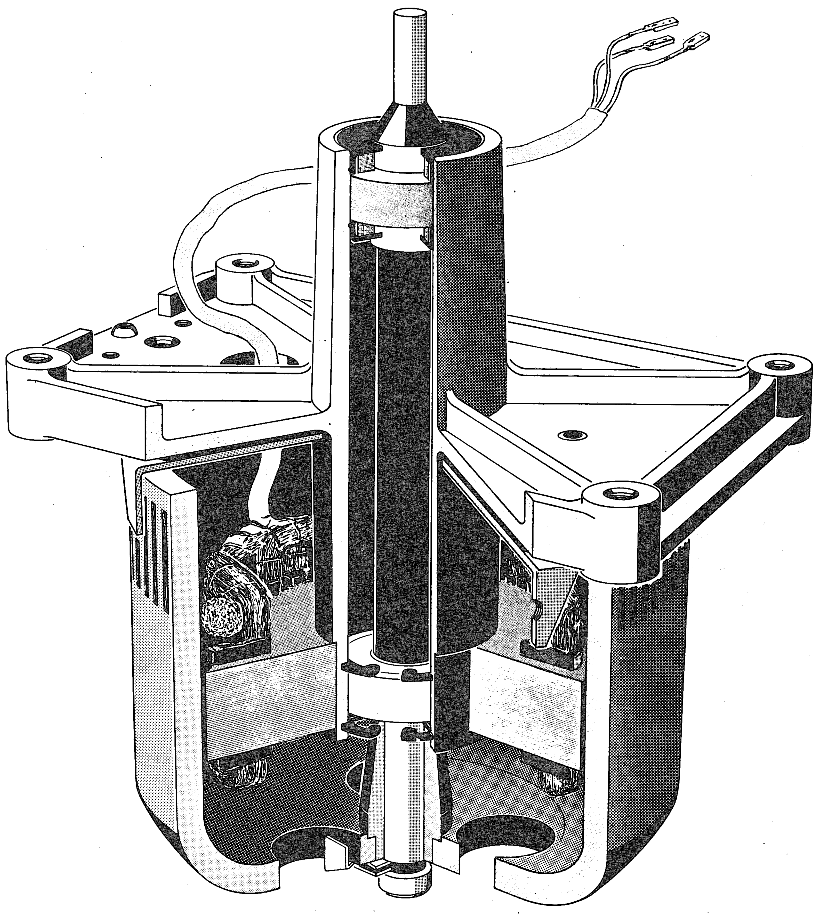

Fig. 1 **Crossection of the motor**

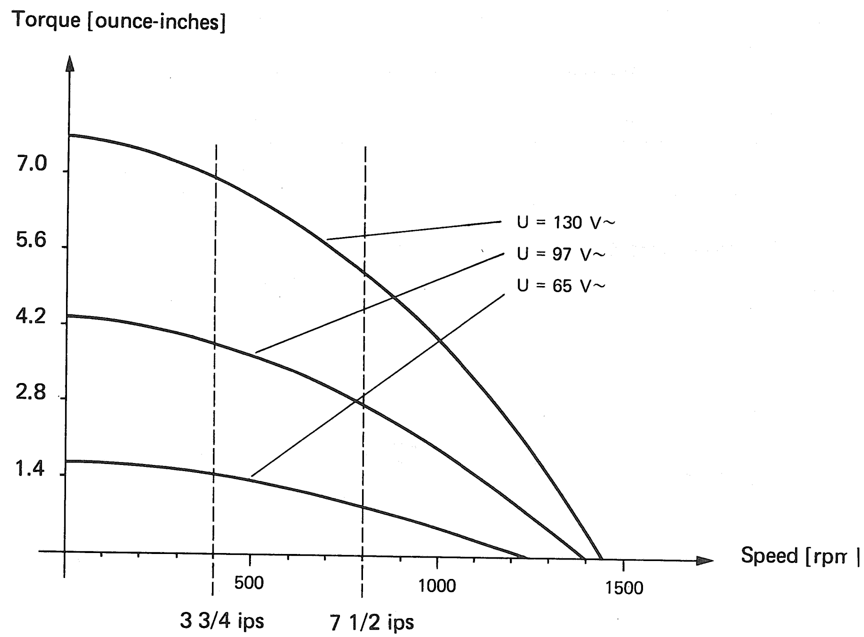

Fig. 2 **Torque in Function of Motor Speed**

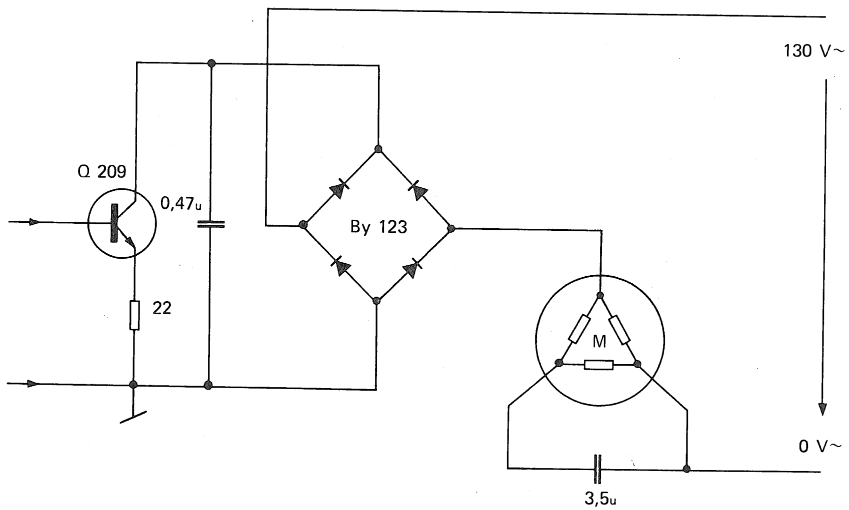

Fig. 3 **Schematic Diagram of the Power Stage**

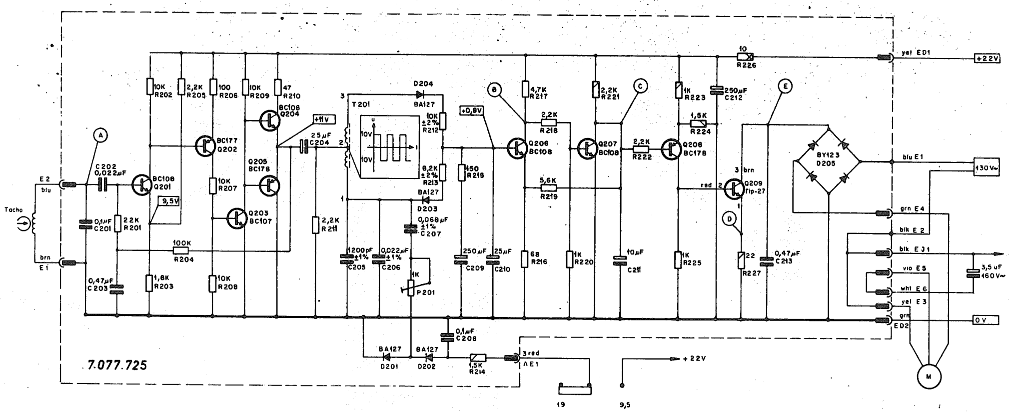

Fig. 4 **Schematic Diagram of the Complete Circuit**

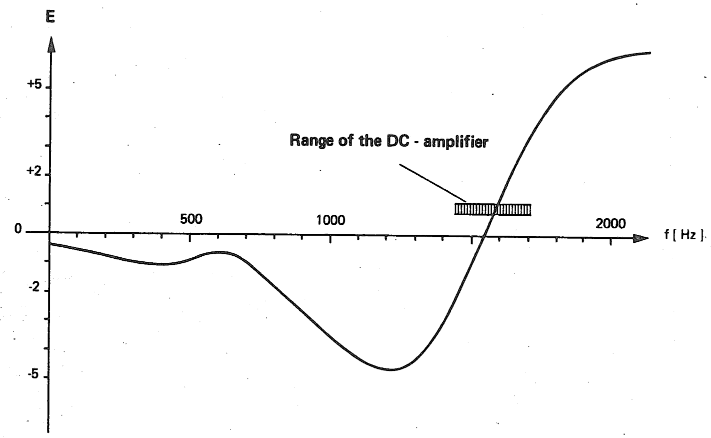

Fig. 5 **Caracteristic of the Discriminator.**

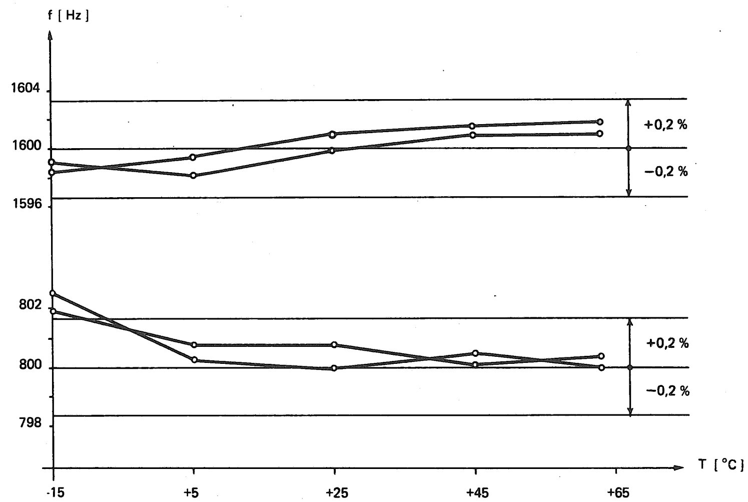

Fig. 6 **Temperature Dependence of the Complete System.**