UDC 621. 313. 392

SMALL HYSTERESIS SYNCHRONOUS MOTORS FOR MUSIC TAPE PLAYERS

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I. INTRODUCTION

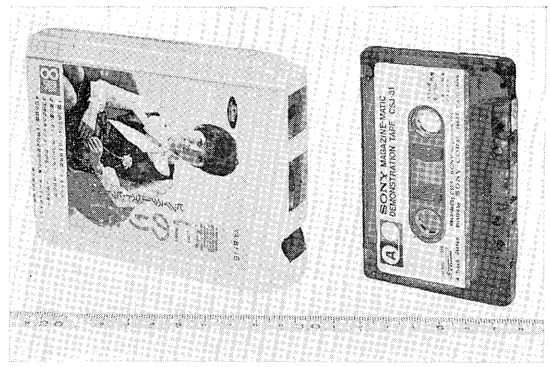
There are various types of synchronous motors, and the hysteresis synchronous motor, which utilizes the magnetic hysteresis phenomenon in a hard magnetic material, theoretically has an almost constant output torque from starting until synchronous speed. Self-starting is also possible, there are few transient vibrations during load changes and the rush current or lock current during starting is also small. These features make it ideal for use as a timer in control equipment including that for sound reproducing equipment such as tape players.

The theoretical analysis of this motor was explored by Steinmetz and later this was considered by Teare, Roters, Copeland, Miyairi, Kataoka, Wakui, Kusakari, Nakamura, Okawa, Kato and others. However, design fundamental is not always established quantitatively, and there are still many difficult problems concerning magnetic materials, processing accuracy etc. Therefore, it has been difficult in practice to plan stable mass production of such motors except in cases where the output is very low. Several years ago, Fuji Electric settled these problems and succeeded in developing two compact high output hysteresis synchronous motors, the FH 41 and FH 42, which can be mass produced. Since this time the production of music tape players has increased remarkably and AC home sets also have become very popular. Because of the support received from the makers of such sets, the production of this type of motor has increased considerably year by year and they will be introduced here.

II. MUSIC TAPES, TAPE PLAYERS AND DRIVING MOTORS

In keeping with the high level of magnetic tape techniques, recording tape became extremely popular due to its portability and the possibility of recording. Although the quality of the sound is not so good than that of disk records, new demands have been created and are increasing rapidly.

Several years ago, an endless 8-track tape cartridge which solved the defects of the open reel type tape



Right: cassette
Left: 8-track tape cartridge

Fig. 1 Music tape cartridge

and the cassette which was developed by the Phillips Co. in the Netherlands who made their techniques available to the public, appeared on the market. As music libraries were built up, the production of these tapes and music player for them increased phenomenally. They have become a major Japanese export and further increases are expected in the future. The 8-track tape cartridges are very easy to use and resistant to vibration, which make them ideal for use in automobiles. Car-stereos using these tapes have become very popular. The cassette tapes are used mainly in portable sets since they are so light and compact. Because of the power supply, a DC micromotor with a mechanical governor is used for the most part in such sets. The main points required of such motors for driving music tape player can be listed as follows.

(1) Constant speed characteristics must be good below the constant required torque.
(2) It must be compact and lightweight.
(3) There must be little noise and vibrations.
(4) There must be little fluctuation in tape speed, i. e., it must have little influence on Wow-Flutter performance of the set.
(5) External leakage fields and magnetic induction to the magnetic heads must be small and the S/N factor good.
(6) It must not be hazardous, when its rotor is locked unexpectedly.

In a DC governor motor, the governor contacts have to operate switching action many times in definite period. (If not, it would result in fluctuation of revolution and consequently good Wow-Flutter performance could not be expected.) It also has brushes and commutator which limit the service life of the motor. For the same reasons, magnetic induction to the magnetic-head is high, machanical vibration may happen rather easily, and the locked rotor input current is large. DC governor motor would not be ideal motor because of problems such as the necessity of fine and skilled governor adjustments accompanying with excellent design to maintain a constant revolution stably against wearing of the contacts and changes of external factors. At present, some research of blushless motors is being carried out by utilizing semi-conductors, but there is still a cost problem.

For some time, excepting very high quality set induction motors, especially shaded pole induction motors which can be produced cheaply and easily, have been used in AC set from the age of open reel type set. They are not constant speed motor. Their revolution is somewhat lower than synchronous speed, and changes more or less by supply voltage and load torque. When they are mounted in set on production line of a set maker, various kinds of pulley with slightly different diameter are prepared, and it is likely necessary that pulley is replaced to keep tape speed within allowable limitation. So there were problems concerning stabilization and rationalization of production line. There were also problems with the S/N factor depending on external leakage flux.

A demand arose for home sets to be able to enjoy 8-track tape cartridges and cassettes in user's home exclusively. Naturally, the motors could be energized from AC commercial frequency power source but they have to be worthy of use for higher quality sets than portable sets and car stereos. Hysteresis synchronous motors which is big dimensionally and rather heavy, had already been used in some large high quality open reel sets.

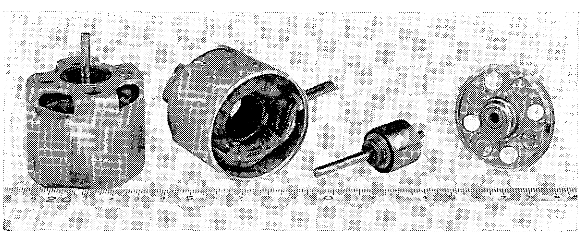


Fig. 2 Hysteresis synchronous motor FH 41

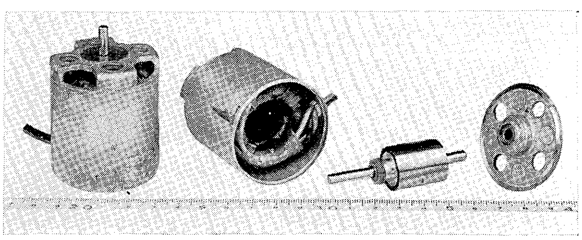


Fig. 3 Hysteresis synchronous motor FH 42

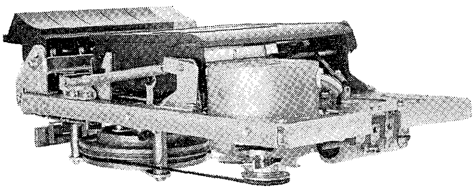


Fig. 4 Tape deck for cassette on which FH 41 is mounted

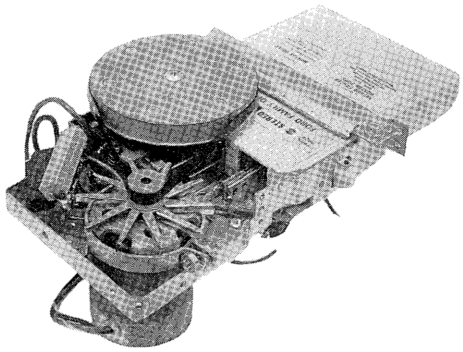


Fig. 5 Tape deck for 8-track tape cartridge on which FH 42 is mounted

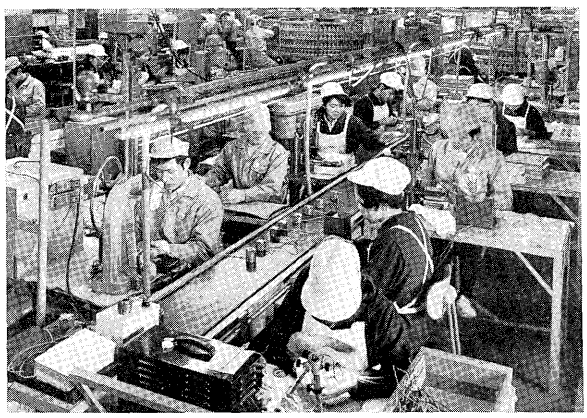


Fig. 6 Hysteresis synchronous motor production line

The FH 42 and FH 41 type hysteresis synchronous motors are developed. They are compact in size and light in weight, and then they can be mounted on 8-track and cassette sets respectively, though the chassis design is unchanged from that of DC set. They meet all of the above requirements and are now being mass produced in accordance with increases in the production of music tape players.

III. PRINCIPLE OF THE HYSTERESIS SYNCHRONOUS MOTOR AND HYSTERESIS RING MATERIAL

1. Principle of the Hysteresis Synchonous motor

The rotor of the hysteresis motor is rather simple in construction. A ring-formed hard magnetic material with large hysteresis loop area at low H (known as hysteresis ring) is assembled on an non-magnetic rotor boss and fixed to a shaft at nonmagnetized condition. The stator which creates a rotating magnetic field in the air gap is arranged opposite the rotor. This stator is very similar to that of an induction motor and can establish a rotating magnetic field by 3-phase winding, if the power source is 3-phase, or by two-phase winding with a phase shifting capacitor, if the power source is single phase. Since the space magnetomotive force waveform has considerable influence on the synchronous torque, it is essential that the stator is of the closed slot to small motor which can not have so many numbers of slots.

When current is flowing in the stator winding, the rotor is magnetized by the stator field then because of the hysteresis phenomenon, a flux density is devoloped lagging behind the stator magnetomotive force. Since when the center direction of the stator magnetomotive force and the center direction of the equivalent pole in the rotor would point to the same direction the space magnetic energy would be larger, a torque is developed in the rotor because of the lagging. Due to the hysteresis phenomenon itself starting torque is developed and its revolution rises up to the synchronous speed which is determined only by the numbers of stator poles and the power source frequency. Under locked rotor condition, magnetized state within each part of the hysteresis ring is exactly equivalent because of its symmetricity and uniformity, then this magnetized state moves on the hysteresis loop at synchronous speed. Even when the rotor revolution is lower than synchronous speed, this relation is not changed and the same torque is developed. Magnetized state within each part of the hysteresis ring moves on the hysteresis loop at difference speed between synchronous speed and rotor revolution speed. When the rotor revolution reaches to synchronous speed, magnetized state within each part of the hysteresis ring becomes as fixed condition to the ring and the same torque is developed as synchronous torque. When the rotor revolution is higher than synchronous speed, this magnetized state within each part of the hysteresis ring is turned reversely and moves on the hysteresis loop, thus braking torque of the same value is developed. In this way, the rotor revolution is maintained at synchronous speed. Therefore, torque characteristics are the same value theoretically from starting until synchronous speed and braking torque of the same value is developed at higher speed than synchronous speed. Since hysteresis motor develops constant torque smoothly, its operation is quiet and its torque form is ideal. In actual motors, however, the theoretical torque form is somewhat disturbed by eddy currents in the hysteresis ring and changing in effective circuits constants in respect to the various revolution speed conditions, especially in single phase motor with leading phase capacitor. In addition, the difference between the pull-out and pull-in torque is very small owing to torque generating form and the ratio of the lock current to the no-load current is very small.

Since the torque of hysteresis motor is developed by magnetization of each parts due to its own magnetic field, higher harmonic component of the space magnetomotive force results in parasitic loss in each part of hysteresis ring. Since this causes the same effect equivalently as if the area of the hysteresis loop were decreased, it is extremely important to minimize the higher space harmonics. Therefore, the balance of ampere turns in each phase winding and the phase angle between them give considerable influence on the motor characteristics. Since in single phase motor employing leading phase capacitors, the relation of ampere turns in the main and auxiliary windings changes during starting and pull-out, it is very important to decide capacitance values and winding specifications so that the best possible relation between ampere turns is maintained at both of these conditions. The optimum winding specifications are difficult to be determined only by calculations. It is necessary to conduct many times of actual tests, and Fuji Electric has established equivalent test methods for changes in the winding and capacitance.

2. Hysteresis Ring Material

The magnetic characteristics of the material used for the hysteresis ring are very important factors in determining the characteristics of a hysteresis motor. The torque is proportional to the loop energy per the magnetization cycle. The relation between the maximum operating field H_p, the flux density B_p in this field and the area of the hysteresis loop E_h can be expressed as follows:

$$\eta = E_h / 4B_p \cdot H_p$$

where η is defined as hysteresis energy factor. Since H_p arises due to the magnetomotive force in the motor stator, it is limited in a certain range which is limited by the input in respect to temperature rises. Any material can be used in which B_p and η are large in this range. Therefore materials with a magnetic coercive force H_c of 100 to 200 oersteds are suitable which is unlike that of usual permanent magents. Fuji Electric uses a material with a little less than H_c 200. Tungsten and chrome steels are not suitable except in motors, of which torque is very low since H_c is too low, common alnico materials are also not suitable because the H_c is too high and the ferrites can not be employed since the H_c is too high and the B_p too low. Examples of materials which are suitable for hysteresis rings include the following:

(1) Cobalt-chrome steels
(2) Special cast magnets of the alnico type (magnets of which H_c is decreased purposely by components and heat treatment)
(3) Special sintered magnets, precipitation hardened

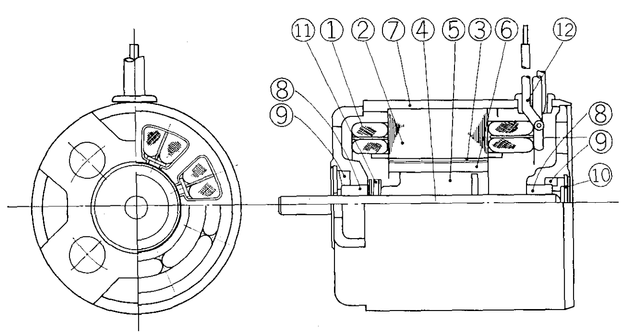
At the time when Fuji Electric began development of this motor, there were only a few types of such magnets but various magnetic makers since that time have developed several magnetic materials which can be used as hysteresis rings. Their work is highly commendable.

The above type of magnets have various features depending on their magnetic characteristics and it is difficult to say which is the best in respect to both machining cost and material costs. Fuji Electric uses all three of the above types depending on the each features. The H_c itself is not so significant on the actual motor performance and the operation loop is the greatest problem. Even though the hysteresis loop from saturation is the same, it still causes considerable difference in low operating loops. It is necessary to decrease this in mass production by operation control. There are also optimum dimensions for the hysteresis ring, i.e. the thickness, and careful design is necessary since the torque will be decreased if the ring is thicker or thinner than this dimension.

IV. CONSTRUCTION OF THE FH 41 AND FH 42 TYPE HYSTERESIS SYNCHRONOUS MOTORS

The FH 41 and FH 42 hysteresis synchronous motors are 4 poles motor, single phase with leading phase capacitors. The standard rated voltages are 117 V 60 Hz and 100 V 50/60 Hz. The outside dimensions are 48 mmϕ × 41 mm for the FH 41 type and 48 mmϕ × 54.5 mm for the FH 42 type. The general construction is shown in *Fig. 7*. The motor is mounted to the chassis by means of a mounting band cramp.

The stator has 8 slots and its winding consist of main and auxiliary windings. To keep winding turns settled is very important for mass production. Winding coils are wound exactly invariably with special winding machines developed for the exclusive use, and are inserted by hand into the slots. Since slot numbers are few, a inner sleeve of soft-magnetic material is inserted inside of the stator core to minimize higher space harmonics. The accuracy of this sleeve and its fitting with the core are very important in respect to the synchronous torque. The previously described hysteresis ring at the rotor is assembled on an aluminum boss and fixed to the shaft. The shaft is made of carbon steel and heat-treated with high frequency device to prevent noise and wear.



① Stator winding
② Stator core
③ Stator inner sleeve
④ Shaft
⑤ Rotor boss
⑥ Hysteresis ring
⑦ Motor frame
⑧ Sleeve bearing
⑨ Wick
⑩ Thrust plate
⑪ Thrust plate
⑫ UL-CSA lead wire

Fig. 7 Construction of FH type hysteresis synchronous motor

The frame is made of a zinc alloy diecast and is treated seasoning treatment. The bearing is specially processed copper base sintered bearing which is impregnated with special synthetic oil. The bearing life is long, stable operation in respect to external temperature changes is possible and noise is minimized. The bearing is of the sleeve type and since processing accuracy is maintained in each part, there is stability against mechanical impact etc. from the exterior.

The insulation of the stator core is a coating system of epoxy resin. Several years ago this process was recognized under File No. E 41200 by the Under writers' Laboratories Inc. (UL) in the United States and was the first process in Japan to receive such recognition of epoxy coating. Every year, reexamination service is conducted for the process. The lead wires which are approved by UL and CSA are used. The entire insulation system is in accordance with UL and CSA requirement.

The shaft side is either up or down according to the set, but there is a difference in the thrust construction. This part is important in minimizing motor vibrations. By shifting the magnetic centers of the stator and rotor, the thrust force is applied in the downward direction. In the shaft side up type, the spherical surface of the shaft tip is supported by a nylon thrust plate. In the shaft side down type, the front surface of the sintered bearing is supported by a laminated bakelite plate, oil-impregnated compressed synthetic fiber material etc. This construction is excellent in terms of noise and service life.

The motor efficiency is quite good, but because of the small size, it is necessary to use a small cooling fan. The construction is comparatively simple but strict quality control is enforced for the materials and each part for stable mass production of high quality products.

V. CHARACTERISTICS OF FH TYPE SINGLE PHASE HYSTERESIS SYNCHRONOUS MOTOR

1. Torque Specifications

At the rated capacitance value and −10% of the rated voltage, the torques are as follows.

FH 41 type, used for playing cassette tapes.
Starting torque: 30 g-cm (0.4 oz-in)
Synchronous torque: 30 g-cm (0.4 oz-in)

FH 42 type, used for playing 8-track tape cartridges.

Starting torque: 70 g-cm (1.0 oz-in)
Synchronous torque: 70 g-cm (1.0 oz-in)

These are standard values but there are also ones of other values which differ in accordance with the demands of the maker based on the construction of the particular tape deck. There are also many types according to the difference in the amount of protrudent length of shaft, attitude of use and direction of rotation.

2. Revolution vs. Torque Characteristics

As can be seen from the examples in *Figs. 8* and *9,* these characteristic form are excellent.

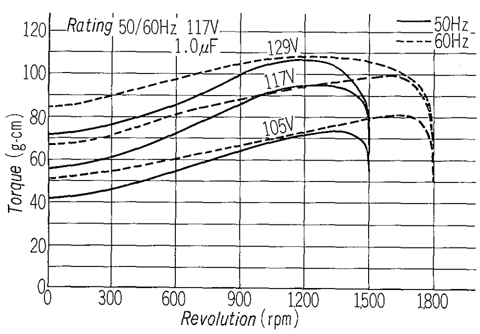


Fig. 8 An example of revolution vs. torque characteristics of FH 41

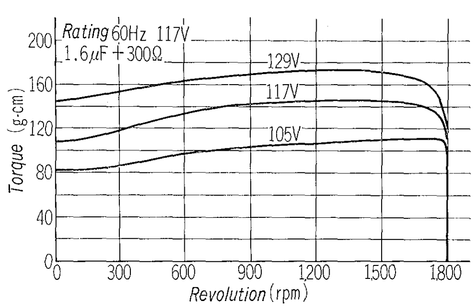


Fig. 9 An example of revolution vs. torque characteristics of FH 42

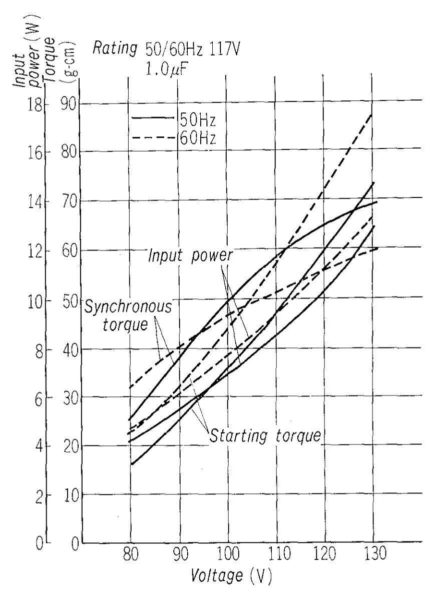


Fig. 10 An example of voltage characteristics of FH 41

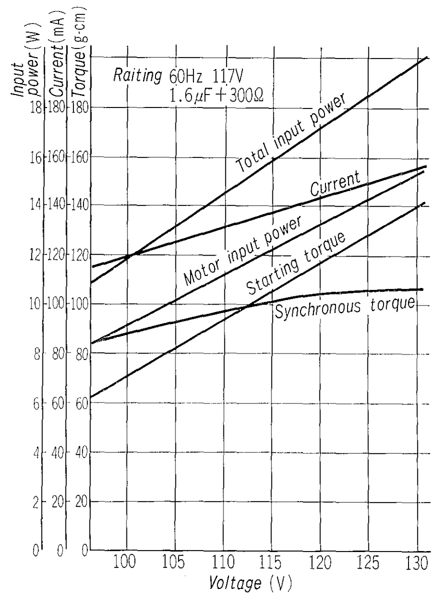


Fig. 11 An example of voltage characteristics of FH 42

3. Voltage Characteristics and Influences of Capacitance Changes

Examples of the influence of voltage change are shown in *Figs. 10* and *11* and those of capacitance changes are shown in *Figs. 12* and *13.* Since there is considerable influence on the starting torque, it is necessary to consider the relation between the necessary torque and the capacitor tolerance.

4. Power Factor

The motors are capacitor run type and the relationship of ampere turns is carefully fixed to achieve a good synchronous torque. Therefore, the power factor is almost 1.

5. Influence of Ambient Temperature Changes

Since the viscosity of the bearing lubricating oil and the temperature of the magnetic material under operation changes in accordance with the ambient

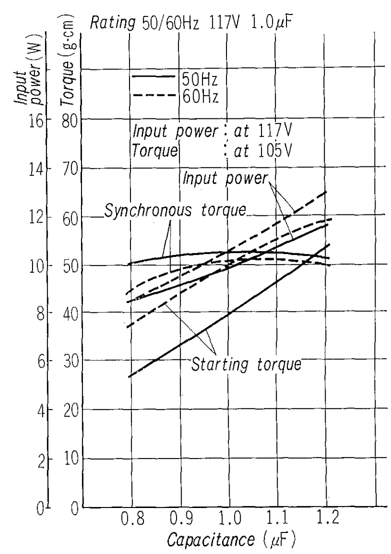


Fig. 12 An example of influence of capacitance change FH 41

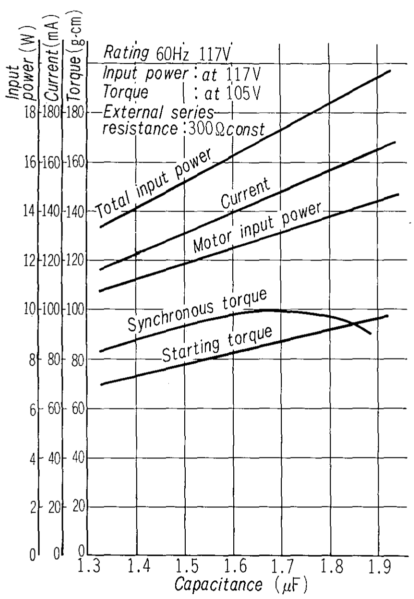


Fig. 13 An example of influence of capacitance change FH 42

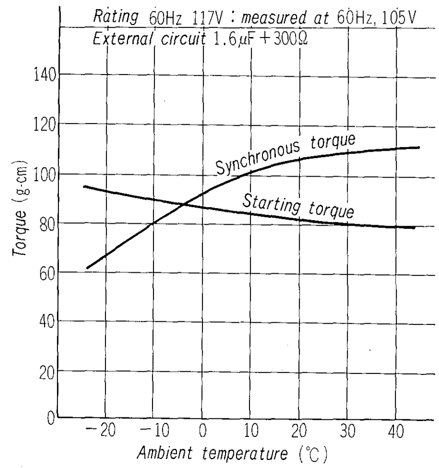


Fig. 14 An example of influence of ambient temperature change

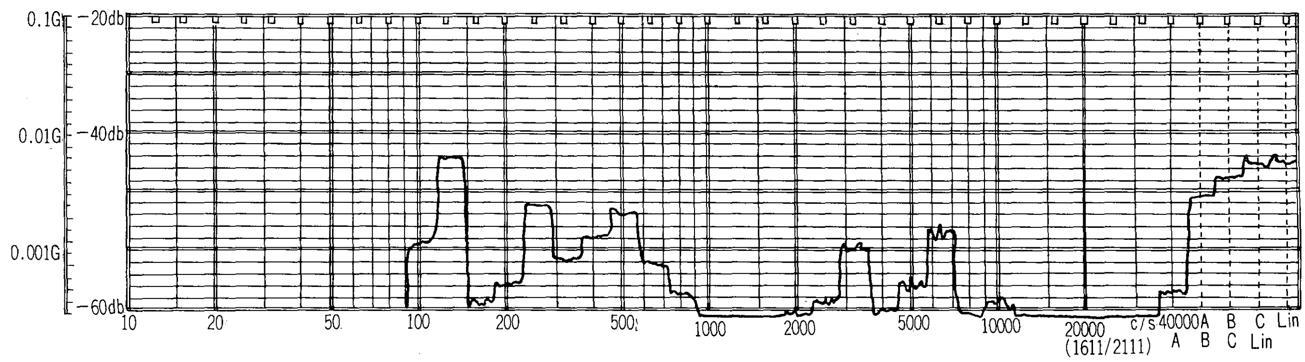


Fig. 15 An example of vibration measurement

temperature of the motor, the torque characteristics at the initial period of voltage applying are also influenced at temperatures below 0°C. *Fig. 14* shows a typical example. When the temperature is lowered, the starting torque increases somewhat but the synchrononous torque decreases. The necessary torque to the tape deck also increases at temperatures below 0°C. Since motor temperature is raised soon due to self-generation of heat by motor loss, though the tape speed decreases somewhat during initial period of operation, in some cases, this presents no problem at actual use in home sets.

6. Temperature Rise

Their temperature rise is within a temperature which can be assured long service life with a small fan. However the condition of the air flow within the actual set differs in accordance with the mechanism design or the way the set is constructed. Temperature rise also differs depending on whether or not another heat source exists near the motor. It is therefore necessary to conduct set assembly test.

7. Vibration

There are almost little vibrations. *Fig. 15* shows an example of vibration measurement data made with an acceleration-type pick-up element attached to the front surface of the motor.

8. Magnetic Induction to the Magnetic Head

Magnetic induction to the magnetic heads due to the motor is small, but since its influence of the heads differ according to the distance and arrangement etc., if necessary, a silicon steel or iron shield plate is placed in front of the motor. In some case, the shape and dimension of mounting band cramp is so worked out, that the band cramp has shielding effect.

VI. CONCLUSION

This article has described a hysteresis synchronous motor which can be used to drive AC set of music tape players whose production has doubled per year in the last few years. It is hoped that quality will improve and expansions in production will be made through the cooperation of every set maker. This motor is also not limited to music tape players. It should find application in cases where such features as small size, high torque and long service life are required.