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Side Loading Microprocessor-Controlled Cassette Deck "DK-70"

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The reliability of automobiles has been improved over the years, and components such as engines perform well for at least one or two years before major problems develop. Car audio products, especially cassette decks, have followed this trend. To meet these new standards of performance, FUJITSU TEN has developed a cassette deck using the latest technology.
This paper introduces the DK-70, a new cassette deck developed by FUJITSU TEN.

1. Introduction

The reliability of automobiles has been greatly improved over the years. For example, the term for automobile inspection was extended from two years to three years. It is also necessary for car audio manufacturers to keep improving the reliability and life of their products.

Factors affecting the life of cassette decks (referred to as decks afterward) are as follows:

1) Change in slip mechanism by aging
   a) Tape entwining because of drive torque reduction
   b) Wow and flutter due to sticking of slip surface
2) Malfunctions, such as tape entwining, due to electric parts failures (motor, plungers, switches, etc.)
3) Defective operation because of a broken belt
4) Defective operation due to abrasion or seizure of bearings

A remarkable extension of product life should occur by solving these problems.

Development of the DK-70 deck was started at the end of 1985. The new deck is a side loading type with high reliability.

2. Aim of development

This deck has been developed aiming at the following points required for car audio products:

1) Improvement of reliability
2) Improvement of operability (feather-touch operation, soft loading)
3) Highest performance possible
4) Reduction of mechanical noise
5) Obtaining freedom of overall product design by making the deck compact, lightweight, and symmetrical

For improved symmetry, a side loading mechanism was adopted.

3. Outline of the deck system

This deck system consists of the deck mechanism, control section and audio section.

For the deck mechanism, new mechanisms, such as cassette holding and side loading, are adopted.

For the control section, a four-bit microprocessor is used as the controller. Electrical parts failures on the deck may cause problems such as tape entwining. The microprocessor has a fail-safe function to prevent such failures. In addition, a serial communication facility for automatic measurement and a watchdog IC for microprocessor control are used.

The audio section uses a grooved head having little contour effect and an equalizer mounted on the side of the deck to decrease motor noise and improve sound quality.

Figure 1 shows the block diagram of this system and Table 1 lists the major functions.

3.1 Deck mechanism

The deck mechanism consists of a cassette loading mechanism (for insertion and ejection), and a tape drive mechanism. Table 2 lists the major components of the deck mechanism, and Figure 2

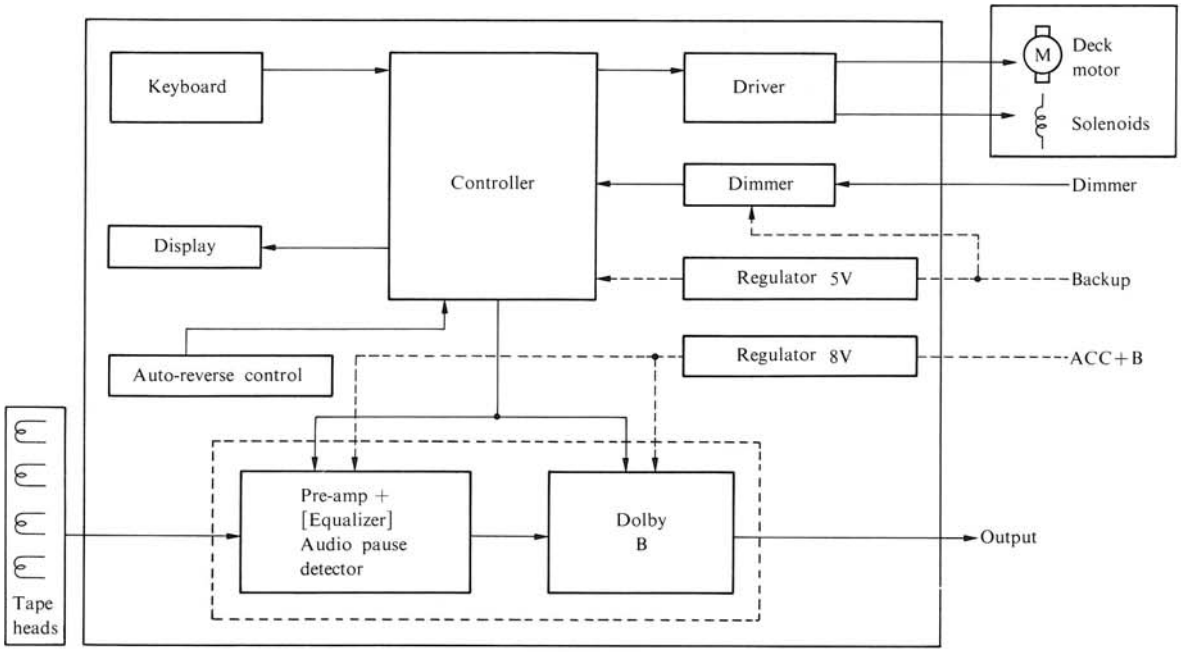

Figure 1. DK-70 system

shows its appearance. Table 3 gives the main specifications.

3.2 Control section

The control section consists of a four-bit microprocessor (MB8851), drivers (motor, solenoids, and indicators), key matrix, and sensors. As stated before, the fail-safe function, watchdog IC, and serial communication function are additional functions provided to improve reliability.

3.3 Audio section

The audio section consists of the heads and equalizers to reproduce the recorded music with high fidelity. The audio section is the main factor in determining the S/N ratio of the deck. Therefore, special consideration was given to decrease the influence of motor noise.

4. Key points of deck mechanism

4.1 Reliability

The parts that affect the life of the deck mechanism include the slip mechanism, motor, belt, and bearings. This section explains the improvements of these parts adopted for this deck.

1) Slip mechanism

Figure 3 shows the conventional slip mechanism and how it was modified for this deck.

Table 1. DK-70 functions

Function	Operation
Basic functions	
FF	Fast-forwards the tape in the play direction.
REW	Rewinds the tape (opposite to the direction of play).
PROGRAM/PLAY	During playback, switches the play direction. (FORWARD/REVERSE)
	During FF/REW, release FF/REW and restores the play direction to the previous direction.
EJECT	Ejection in all modes
Music selection	
APS	Skips forward or backward by one music from the one being played.
Protection	
Prevention of slack	Eliminates tape slack during loading.
Fail-safe	Detects abnormalities of electrical parts (motor, plungers, switches, etc.), and ejects the cassette or puts the cassette into STAND-BY state.
Watchdog	Detects abnormalities, such as latch-up, of the microprocessor, and initializes the microprocessor.
Other functions	
Powered ejection	Ejects the cassette using the capstan motor and gears.
Tape end detection	Detects the end of the tape, and switches the run direction.
Dimmer	Varies the luminance of indicators.
Key-off standby	Releases the pinch roller when ACC is off.
Serial communication	Enables automatic measurement and remote operation.

Table 2. Deck mechanism components

Mechanism	Major components		
	Drive Sources	Sensors	Others
Loading mechanism	Capstan motor (also used for tape drive) CH switching solenoid (also used for tape drive mechanism)	Insertion start/eject end detection switch – Insertion end detection switch – Head base switch	Reduction gears Levers
Tape drive mechanism	Capstan motor Head forward/backward drive solenoid Head holding solenoid CH switching solenoid	Magnetic head Drive direction detection switch Magnetic reluctance switch	Capstan shafts Belt Pinch rollers Slip mechanisms Reduction gears

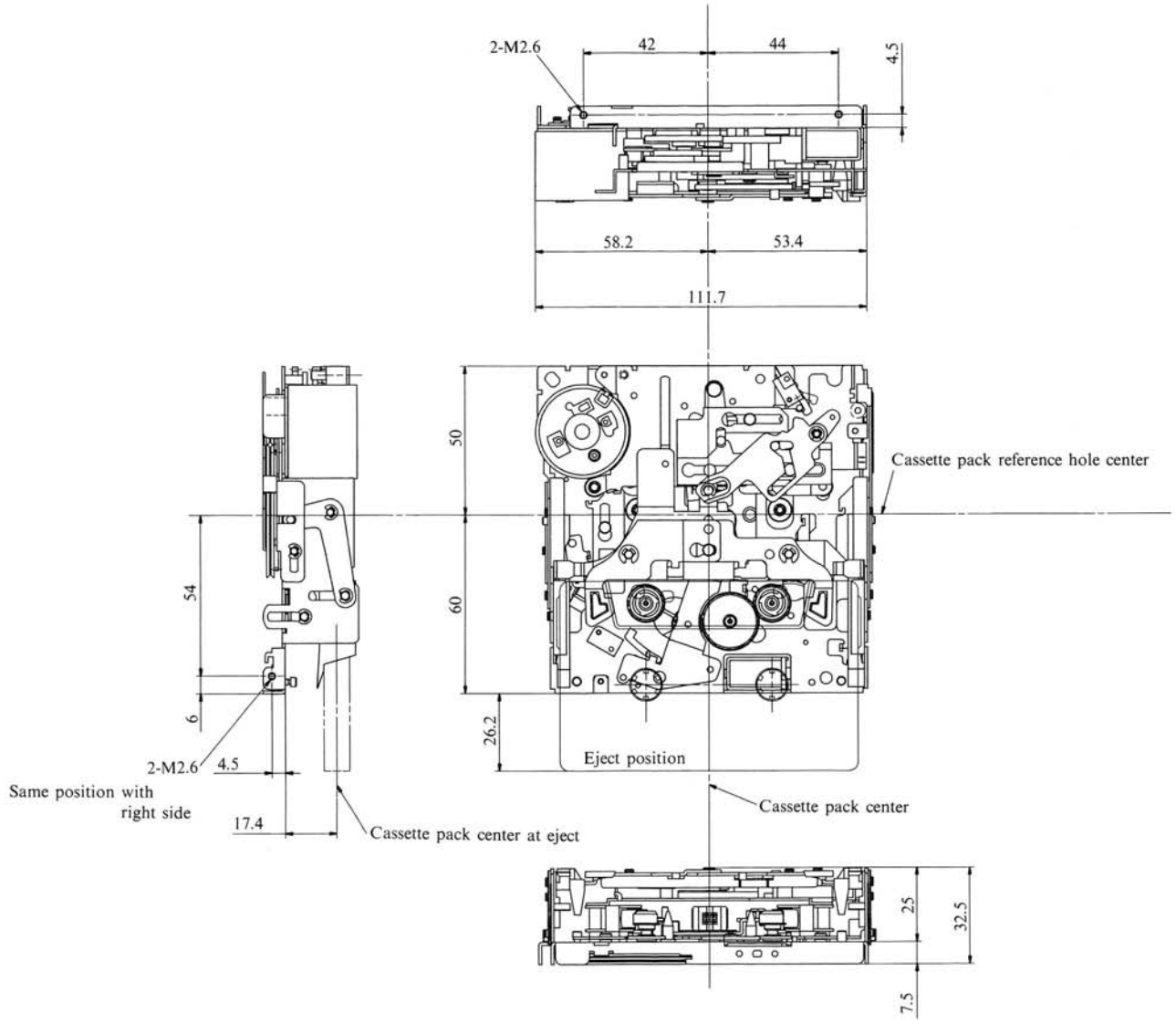

Figure 2. DK-70 outline

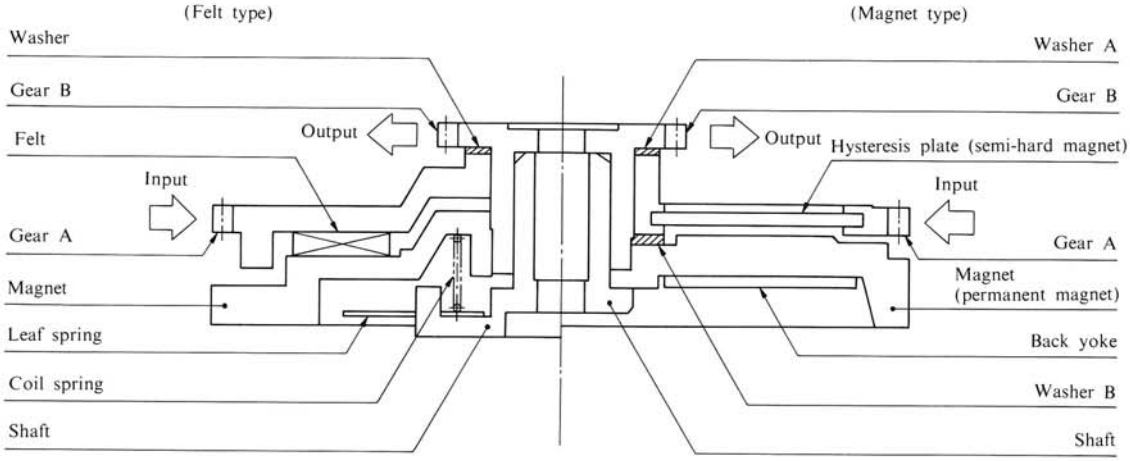

Figure 3. Slip mechanisms

Conventional slip mechanisms experience the following problems because the torque is generated by the friction of felt and resin:

a) Torque varies largely immediately after assembly (concordance of the contact part of felt and resin).
b) Torque varies largely with aging and changes in environment (change of friction factor).

In the magnet type which is adopted for this deck, the contact part is minimized as compared to the felt type, and the torque is generated by magnetic force (hysteresis energy) between the permanent magnet and the hysteresis plate (semi-hard magnet). This technique suppresses the change of torque mentioned above.

Figures 4 to 8 show the magnetized pattern of the magnet, the hysteresis characteristics of the

Table 3. Deck specifications

Item	Description
Rating etc.	
Deck type	Side loading auto reverse
Operation	Feather-touch operation
Dimensions	106.8(W) × 32.3(H) × 110(D) (mm)
Weight	420 g
Reproduction mode	4-track 2-channel
Tape used	Compact cassette of Philips standard
	Tape thickness: 10 to 20μm
Tape speed	4.76 cm/s
Power supply voltage	13.2 VDC
Performance	
Wow and flutter	0.2% WRMS or less
Frequency characteristics	1 kHz reference : 12.5 kHz : 0 dB to −4 dB
Winding torque	45 to 70 g-cm
FF/REW torque	55 g-cm or more
Tape driving force	80 g or more
FF/REW time	110 s or less (C−60)

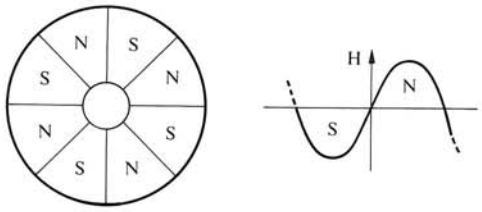

Figure 4. Magnetized pattern of magnet

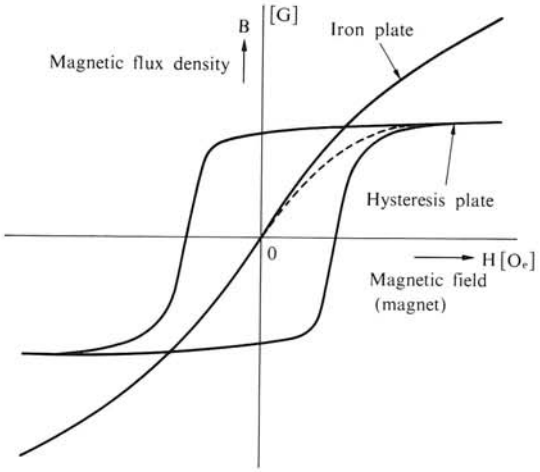

Figure 5. Hysteresis of hysteresis plate and iron plate

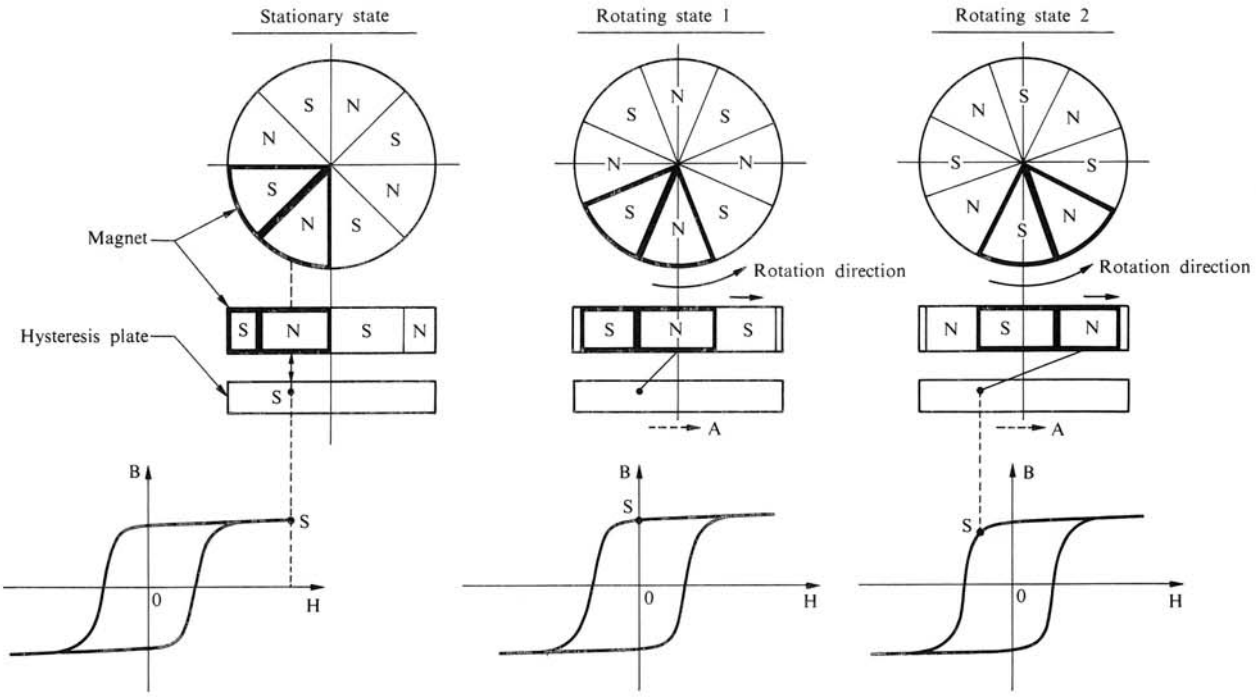

Figure 6. Principle of non-contact slip mechanism

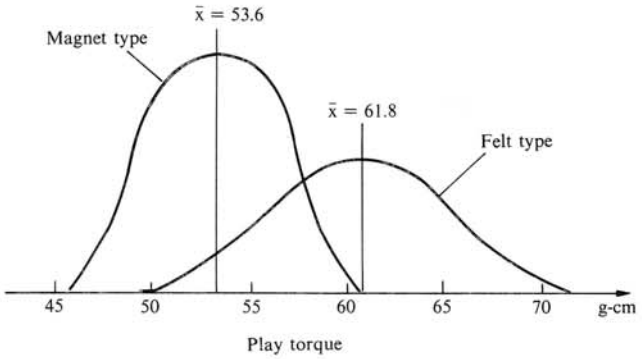

Figure 7. Dispersion of initial torque

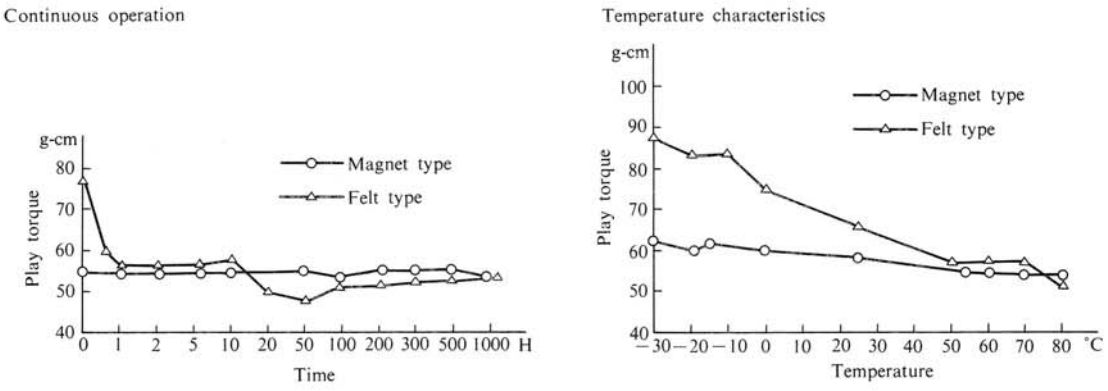

Figure 8. Aging and temperature characteristics of play torque

hysteresis plate, the principle of torque generation, the initial torque, and the results of continuous operation and temperature tests.

2) Capstan motor

This deck uses a two-governor motor as the capstan motor. The two-governor motor has a longer life than the one-governor motor. To extend the life further, the design load of the motor is reduced. (Only one belt is used.) To improve performance and reliability, it is also possible to use an electric governor motor or FG servo motor. Figure 9 shows the one-governor and two-governor motors; Figure 10 is a comparison chart. The two-governor motor is not affected much by position, and it has excellent vibration resistance. In addition, the self-cleaning function prevents con-

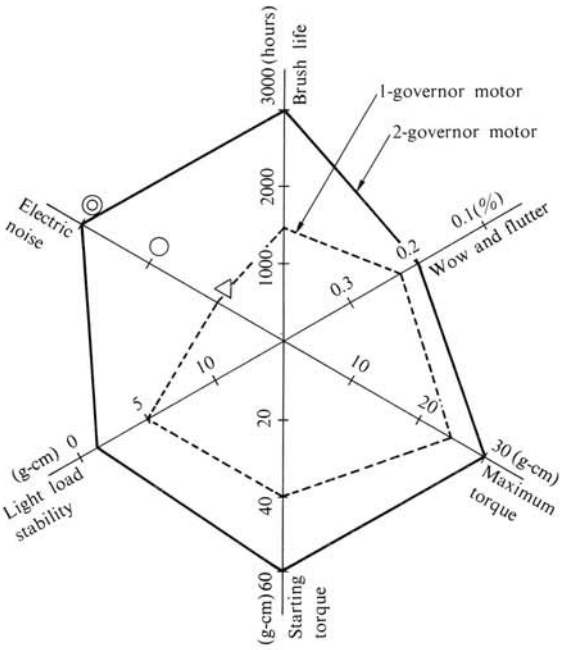

Figure 10. Motor characteristics comparison

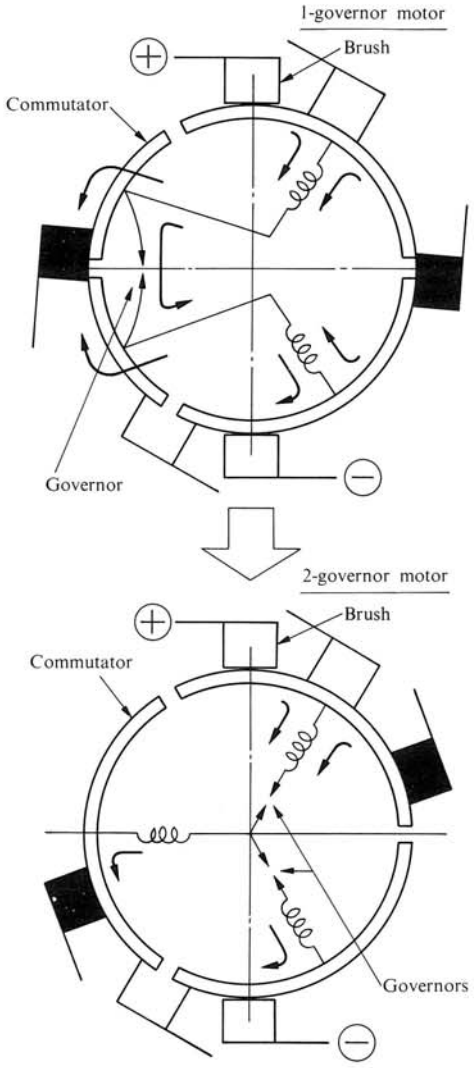

Figure 9. Structures of motors

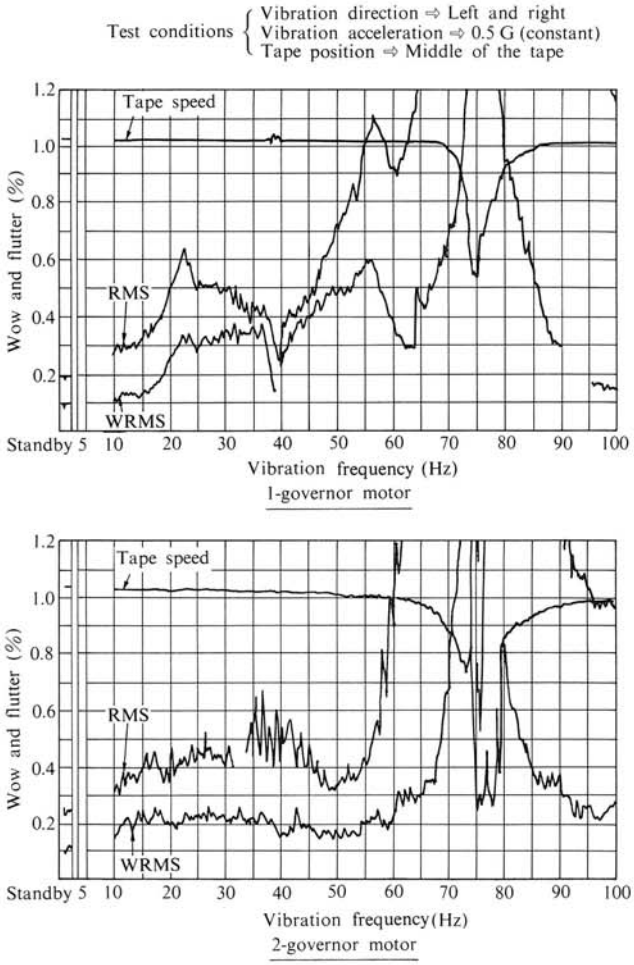

Figure 11. Wow and flutter vs. vibration

tamination of the commutator. This function protects against tape speed abnormalities. Figure 11 shows the wow and flutter characteristics vs. vibration.

3) Belt

A new material was used for the belt to improve the tensile break strength and extend the life. Figure 12 is a comparison chart for the conventional and new belts.

4) Bearings

Oil-free bearings are already in use for conventional decks. However, seizure of bearings occurs due to the loss of oil during continuous operation at high temperature. A solid lubricant (graphite) is used for the bearings in the DK-70 to prevent seizure and extend the life. Figure 13 shows the bearing structure and the predicted life with Weibull probability paper.

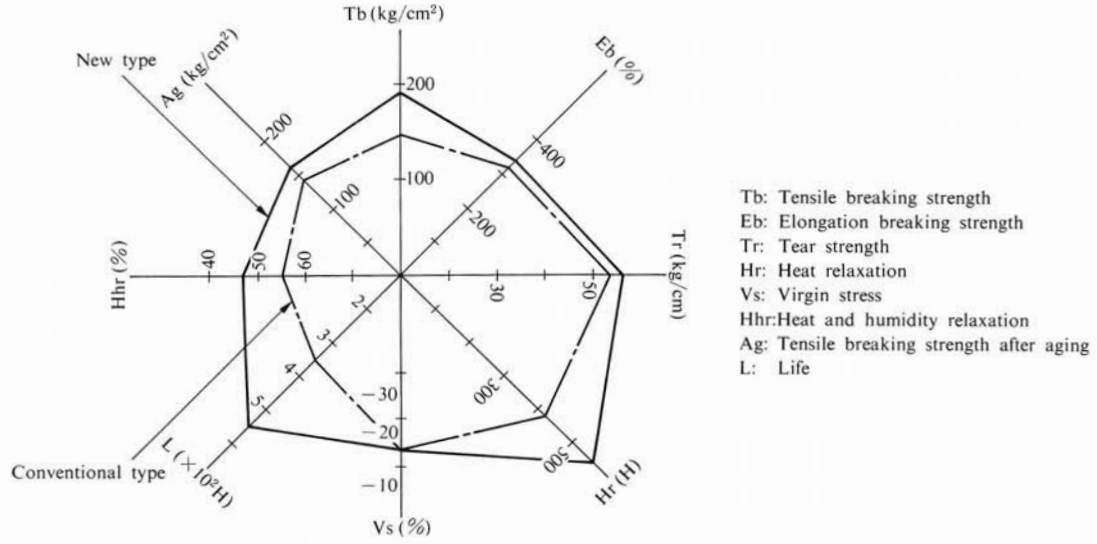

Figure 12. Belt characteristics comparison

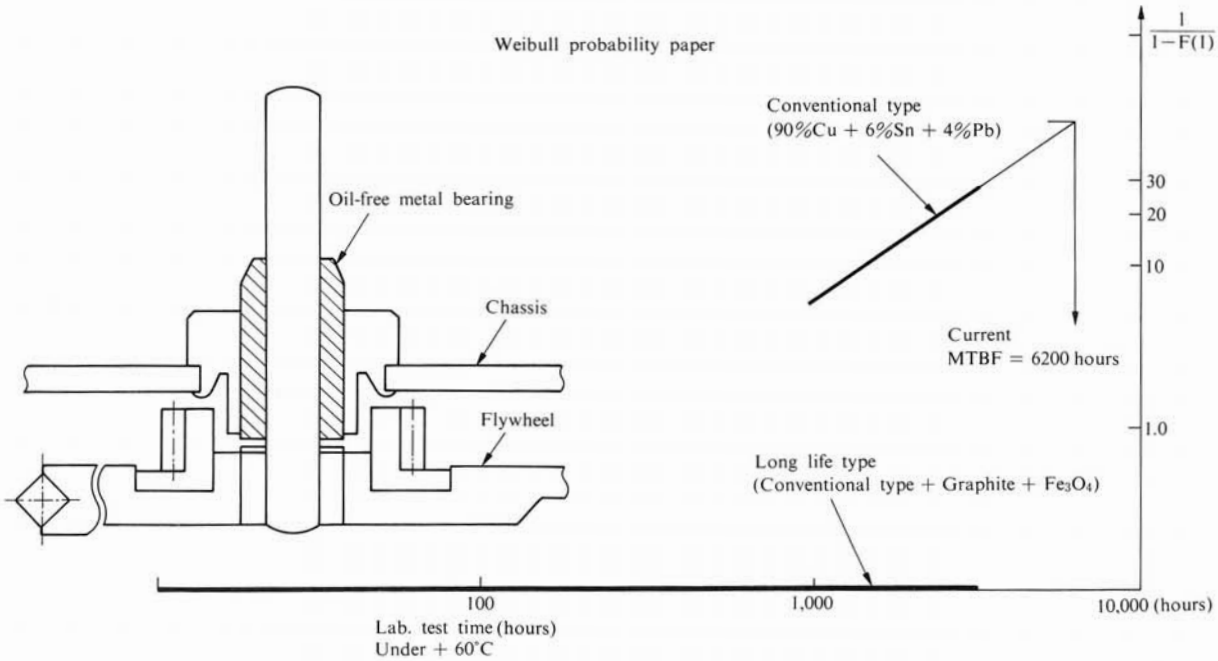

Figure 13. Long life oil-free metal bearing

4.2 Operability

Operability is also an important factor. This deck has feather-touch operation. A soft loading and power ejection mechanism by using a capstan motor is used for cassette insertion/ejection.

1) Soft loading and power ejection mechanism

This deck has a power ejection mechanism with end loading. For conventional decks with end loading, auto loading by a loading motor or manual insertion (pushing the cassette in by hand) and manual ejection (ejection by operation lever) or power ejection are adopted. The loading motor type costs more to produce than the manual type, but is much easier to use. The DK-70 adopts the insertion system by using a spring and the power ejection system by using gears. At insertion, the drop speed of the cassette is reduced by using gears for ejection. The impact noise at dropping is thus reduced, improving the insertion operation. Figure 14 shows the principle of this mechanism.

2) Cassette holding mechanism

As the function appended to the loading mechanism described above, a mechanism to hold the cassette tape at insertion is required. Figure 15

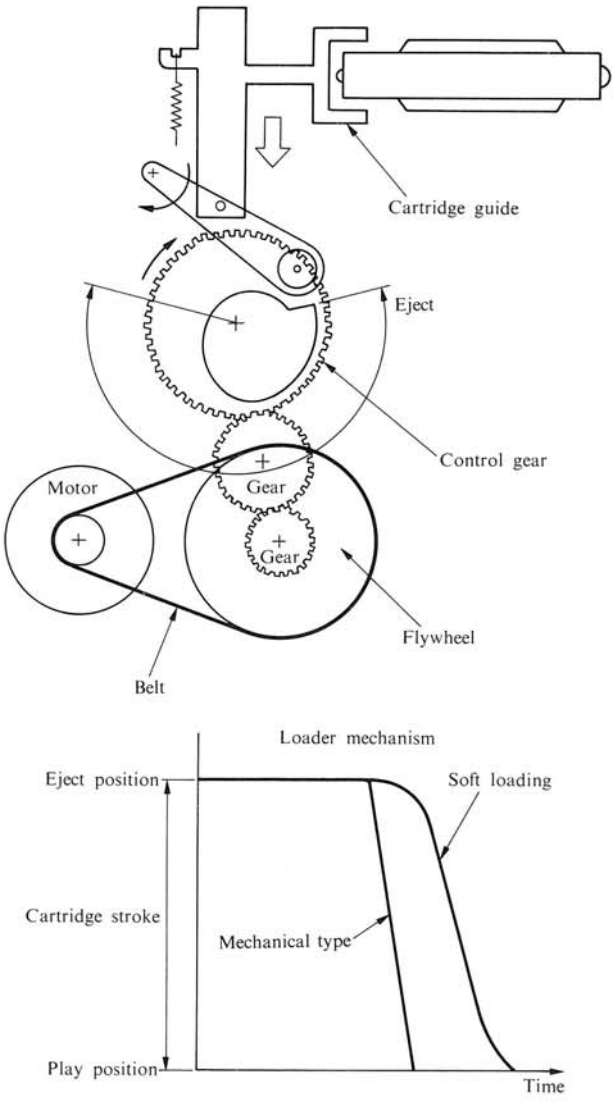

Figure 14. Soft loading and ejection mechanism

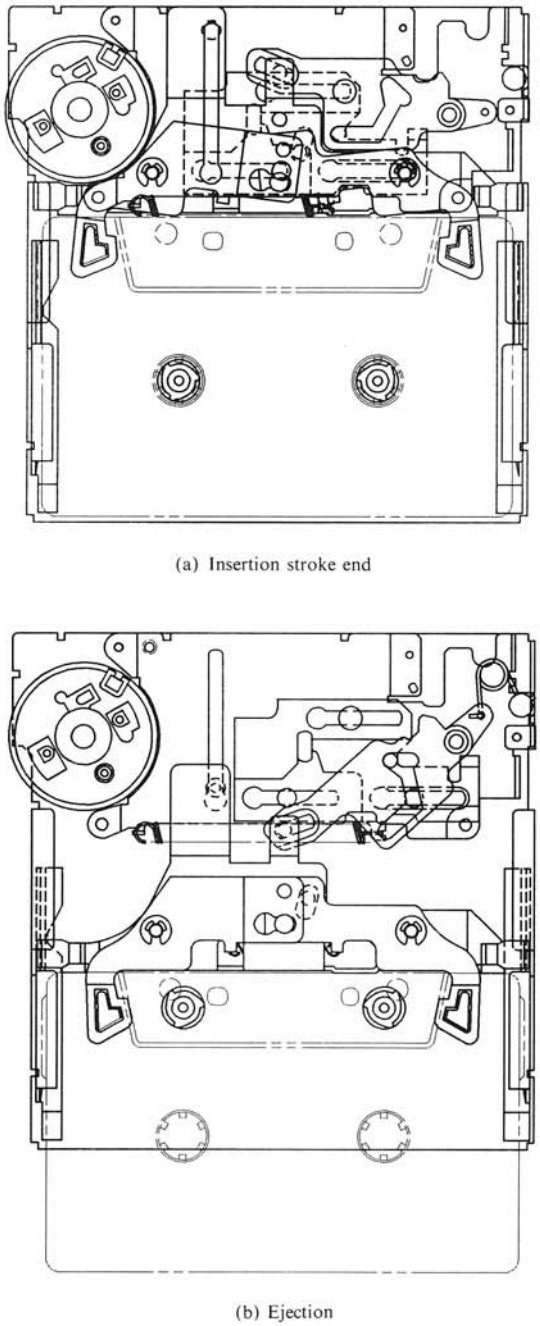

Figure 15. Cassette holding mechanism

shows such a cassette holding mechanism. Its features are explained below.

a) To reduce the height of the cassette deck, the raised portion of the cassette is used to grip it.
b) By connecting the left and right levers with a spring, the cassette can be held even if the dimension of the cassette has errors.
c) The left and right levers to hold the cassette are opened at the position where the holding mechanism moves to the stroke end and the cassette drops. This operation eliminates insertion errors.

4.3 Performance

A dual azimuth mechanism was adopted because of its cost performance and high quality sound reproduction. Figure 16 shows the principle of this mechanism and its frequency characteristics.

4.4 Other characteristics

Mechanical noise is also a large problem to users. This deck adopts the following to reduce mechanical noise:

a) Low-speed drive mechanism
b) Resin gears for flywheel
c) Combination of gears made of different materials

Especially for c), polyacetals and nylon are combined to lower the coefficient of kinetic friction between gears, thus reducing noise.

5. Key points of control section

Chapter 3 explained the outline of the control section. This chapter explains the fail-safe function, watchdog IC, and serial communication: these are key points of the control section.

5.1 Fail-safe function

The fail-safe function forces the microprocessor to monitor the status of the electrical parts (motor, plungers, switches, etc.) of the deck during operation. If one of the parts breaks down, this function immediately puts the deck into standby status or ejects the cassette. This function prevents secondary

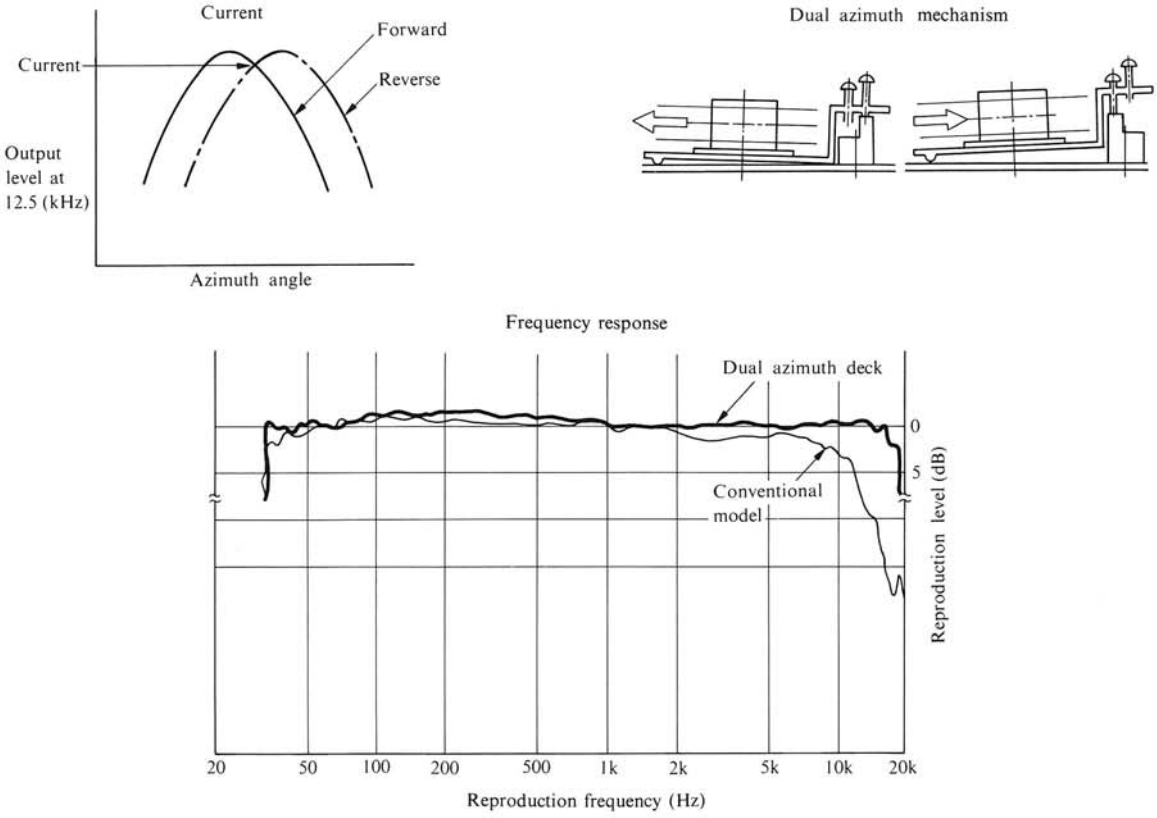

Figure 16. High-fidelity reproduction with a dual azimuth mechanism

failure and minimizes the fault if a problem occurs in the deck. The following sections outline the fail-safe function.

5.1.1 Specifications

1) We prepared a two-dimensional check list for the failure mode (open or short circuit) of the electrical parts of the deck and the deck operation mode. See Table 4. Then, we examined the conditions of the deck in each combination.
2) The tests helped prove that plungers were burned out by repeating on/off operations and that tape twining occurred depending on the mode combination.
3) To prevent the above failures, the program for the microprocessor was modified so that the following functions operate:

– If a combination condition other than those marked with a circle (indicating normal operation) in Table 4 occurs, the cassette is forcibly ejected.
– If the cassette cannot be ejected, the deck is forcibly put into standby status.

5.1.2 Program flowchart

Figure 17 shows the flowchart of the microprocessor program for the PLAY mode. For other modes, the same idea is applied.

5.2 Watchdog IC

1) The watchdog monitors the status of the microprocessor, and resets the microprocessor if an abnormal condition occurs such as latch-up.
2) A pulse is output in each machine cycle from the output port of the microprocessor, and the watchdog IC monitors the pulses. If latch-up occurs and the pulses are interrupted in some cycles, the watchdog IC resets the microprocessor to normalize it.

5.3 Serial communication

The advantages of serial communication are as

Table 4. DK-70 operations in defective status

Defective status	Operation				
	Tape insertion	PLAY	PLAY→PRO	PLAY→FF	PLAY→REW
Head base position detection switch					
Open	○	○	○	Play begins after temporary stop.	Play begins after temporary reversal and return to original state.
Short	○	○	○	Ejected	Motor stops after reversal. (Indication is not cleared.) Ejection is not accepted.
Insertion start swtich (ejection end)					
Open	Pack does not drop. Ejection is not accepted.	Stop Indication is not cleared. Ejection is not accepted.	–	–	–
Short	Pack drops. Normal after insertion ends.	○	○	○	○
Insertion end switch					
Open	Standby state after pack drops. Ejection is accepted.	Standby state Ejection is accepted.	–	–	–
Short	Pack drops, but head advances too fast. Normal except for the above.	○	○	○	○

follows:

a) Can be used for automatic measurement in combination with a personal computer.
b) Remote operation is possible from the outside of the test equipment, such as the thermostatic chamber, during reliability testing.

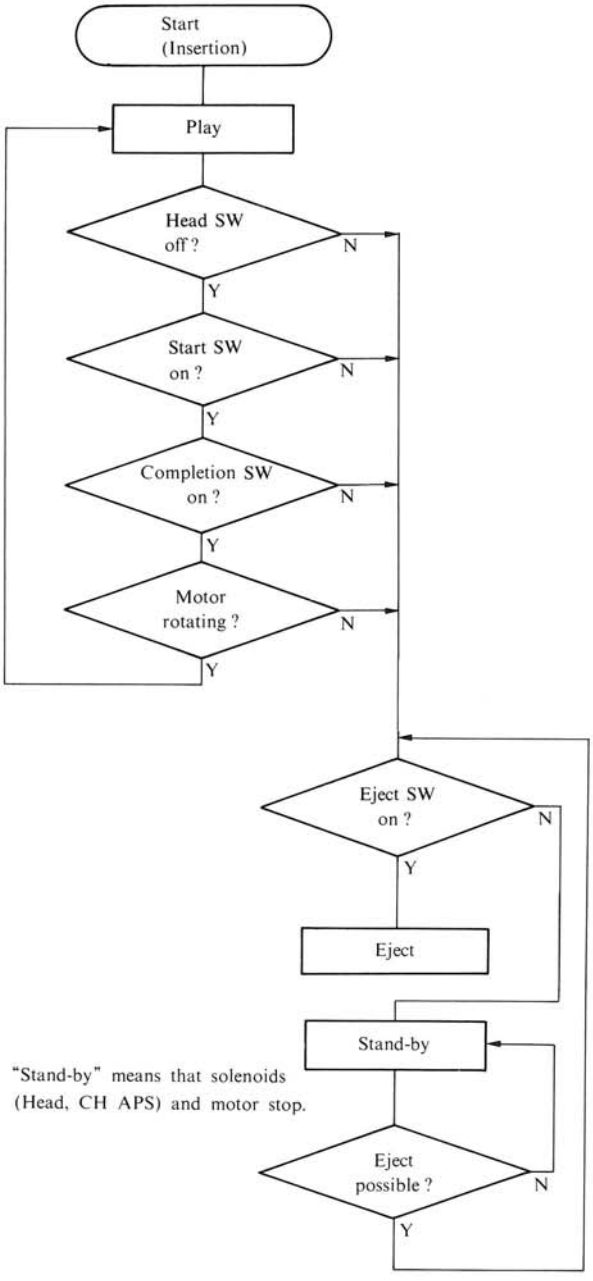

Figure 17. Control program flowchart example

As shown in Figure 18, the communication information consists of three types of signals (clock, data, and answerback). Data consists of four-bit words.

5.3.1 Application to automatic measurement

We made a test tape on which the signals for all test items of the deck were recorded. (See Figure 19.) By combining it with a personal computer as shown in Figure 20, automatic measurement under computer control became possible. This function eliminated manual measurement errors in the production line. The insertion/ejection time for test tape replacement for each test item became unnecessary; the total measurement time was reduced to 1/4.

5.3.2 Remote operation

For the temperature test in the reliability tests, the deck is placed into a thermostatic chamber and its operations are checked. In the past, the door of the thermostatic chamber had to be opened frequently to operate the deck during testing. By using the serial communication function as shown in Figure 21, remote operation can be performed by the remote control board or personal computer. With this function, the door of the thermostatic chamber need not be opened during testing, enabling effective evaluation.

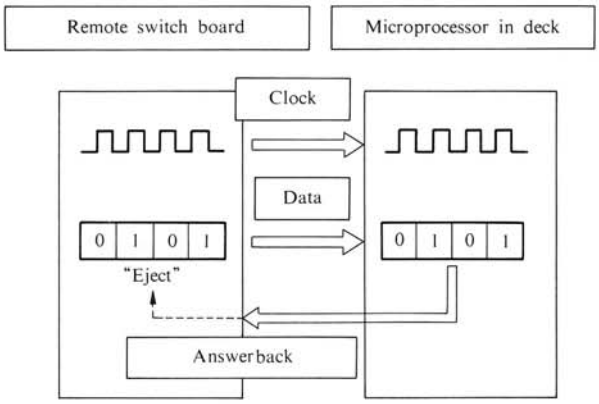

Figure 18. Serial communication

Freq. No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	(23~421)	422
Freq. & Track	Full	7k/4k/(400)/4.2k/B														B/3k/5.4k/(1k)/5.6k/63/5.8k/10k/(F2~22)x19/7k									
	Tr-1						4.4k	1k	4.6k		4.8k	1k	5k	1k	5.2k										
	Tr-2						4.4k		4.6k	1k	4.8k	1k	5k	1k	5.2k										
	Tr-3						4.4k		4.6k	1k	4.8k	1k	5k		5.2k										
	Tr-4						4.4k	1k	4.6k		4.8k	1k	5k		5.2k										
Time (s)		10/1/(1.5)/1/3					1	1.5	1	1.5	1	1.5	1	1.5	1	3/8/1/(1.5)/1/2/1/1.5/(693.5)/10									
Level (dB)		−10/−10/(0)/−10/B					−10									B/−10/(0)/−10/(0 & − 10dB)/−10									

Figure 19. Test tape format

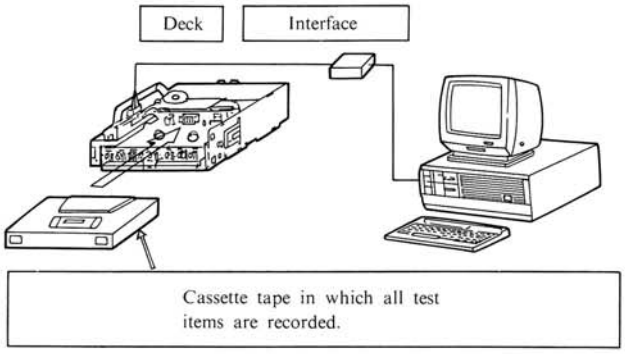

Figure 20. Test using serial interface

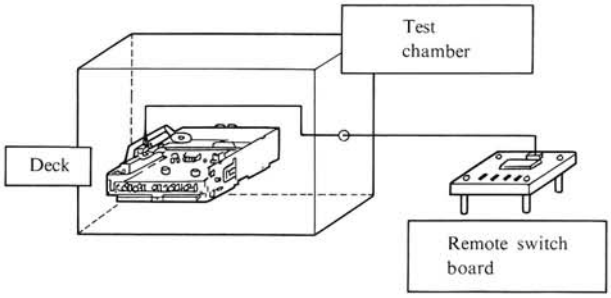

Figure 21. Remote test control

6. Key points of audio section

The audio section consists of the head, which reproduces the signals magnetically recorded on tapes as electrical signals, and the equalizer, which amplifies the electrical signals according to the de-emphasis characteristic. The characteristics especially related to the quality of sound are explained below.

6.1 Grooved head

For a cassette deck, the waviness called the contour effect occurs in the output level at low frequencies. This waviness is mainly caused by the shape of the head. The contact part with tape of the grooved head is smaller than that of the conventional round-type head. The grooved head is thus effective in reducing the contour effect as shown in Figure 22.

6.2 Equalizer mounted on deck

The signals reproduced by the head are low level (e.g., about 0.5 mV for the tape of standard recording level). The signals are thus easily affected by motor noise. However, the signals from the equalizer are not as affected by the noise because they have been amplified to about 100 times at 1 kHz. In the DK-70, the equalizer is mounted on the deck to minimize the distance between the head and equalizer. This improves the sound quality.

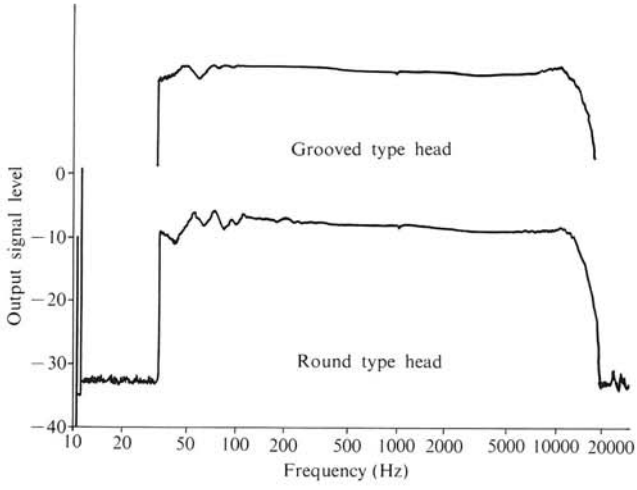

Figure 22. Reduced contour effect

7. Evaluation of reliability

For developing the new deck, we reviewed the method of evaluation. Previously, several evaluation tests were executed concurrently, and the deck used for one test was not used for other tests. This method is not practical because in actual use, the decks are used under various conditions. For this reason, we adopted the serial test system, with which a sample is evaluated under various conditions. Table 5 lists the test items. Consideration is given so that the load on the mechanism increases step by step. For example, the temperature test which requires only a few operations is executed first, and the operation endurance test, a fairly complex one, is executed last. Figure 23 shows the typical items of the serial test results.

Table 5. Test items and test quantity

Test item	Handmade proto-type (units)	Product by tentative die (units)	Product by mass production die (units)
1. Initial characteristics	5	29	32
2. Long duration temperatures tests			
① Temperature test (general)	5	5	5
② Storage at low temperature	–	5	5
③ Storage at high temperature	–	5	5
④ Storage in high humidity	–	5	5
⑤ Thermal shock	–	5	5
⑥ Operation at low temperature	–	5	5
⑦ Operation at high temperature	–	5	5
⑧ Operation durability	–	5	5
⑨ Overhaul check	–	5	5

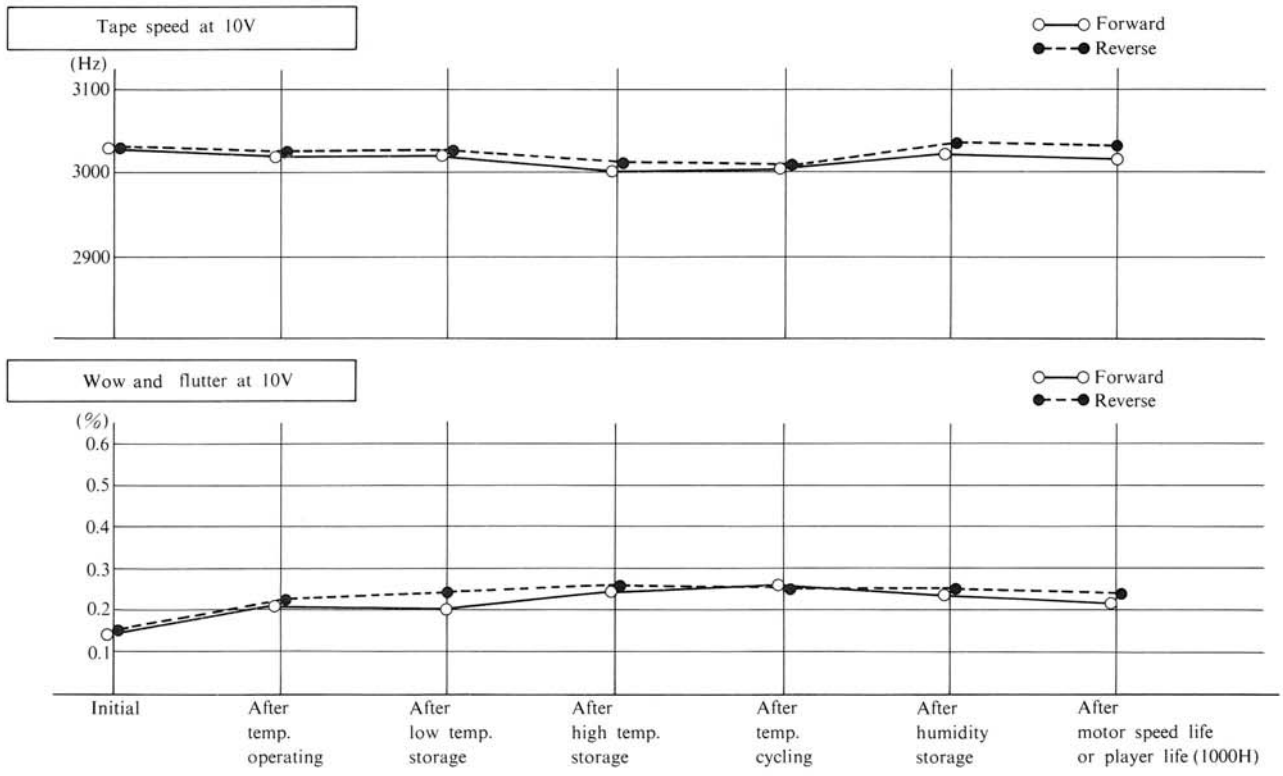

Figure 23. Serial test data (Examples)

8. Conclusion

A product that could pass the new evaluation method was developed by adopting new mechanisms and improving the control section. However, cost reduction is an important problem. In the future, new ideas for reducing cost without degrading performance and reliability will be examined. For example the magnet-type slip mechanism is comparatively high in cost because a hysteresis plate (semi-hard magnet) is used. It is necessary to examine the material of the hysteresis plate. Even with the conventional structure (felt type), it may be possible to double the life without increasing cost if the slip surface is doubled (double-sided slip). Using an electronic governor motor with a simple structure in place of the mechanical governor motor will also reduce cost and extend the life. Although the electronic governor motor has poor load variation (temperature characteristics), it can be put to practical use by decreasing the load of the mechanism. This point was also considered when designing the DK-70. As stated above, there is yet room for examination. The product should be further improved concerning the quality, performance, and cost.

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