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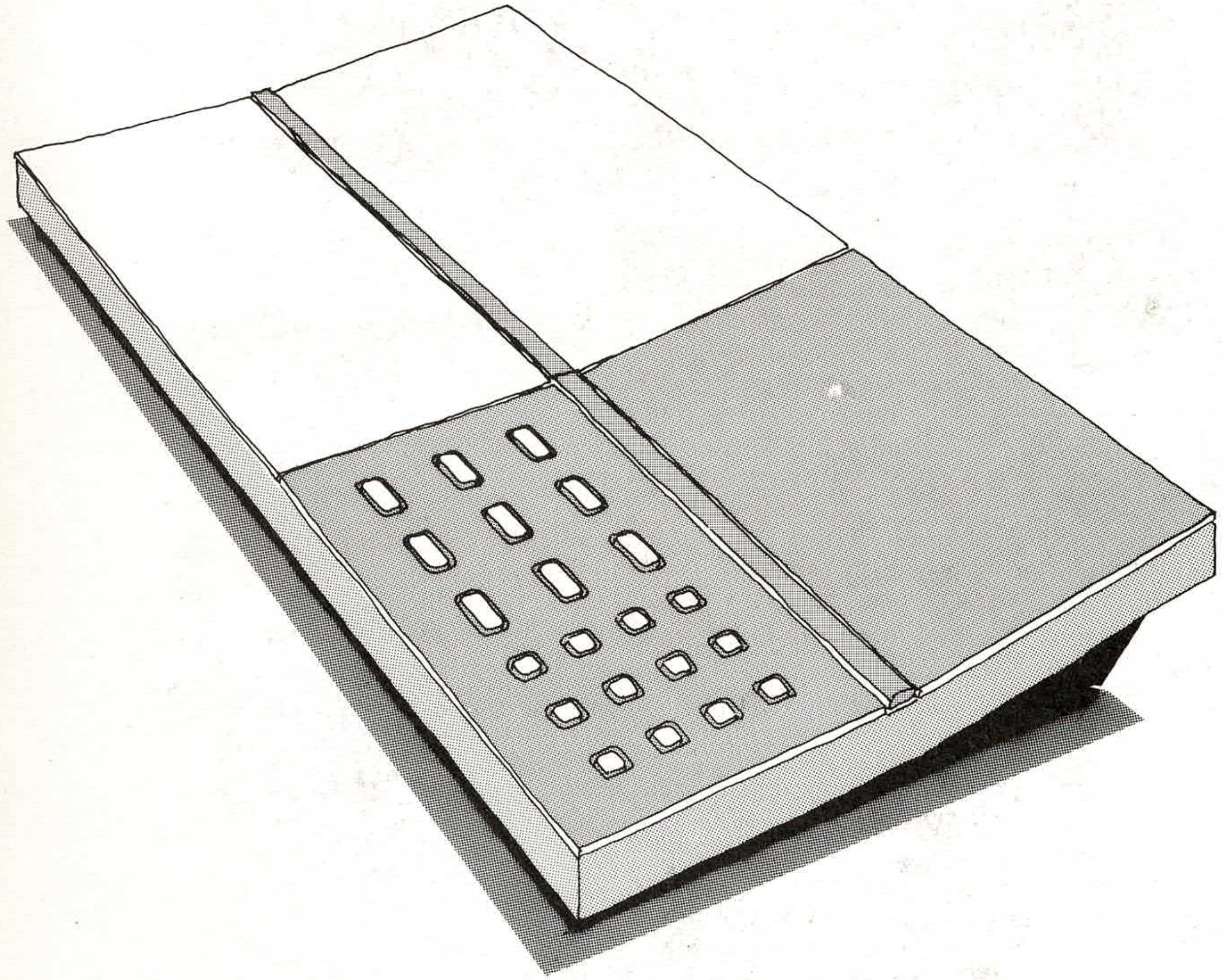

BANG & OLUFSEN
DESIGN STORY
BEOCORD 8000.

SKP/MGE/ 02-80

Three years ago, in 1975, a small team at Bang & Olufsen started planning the next generation of cassette tape recorders. Based on the design experience gained in developing the Beocord 5000 which it replaces, the Beocord 8000 was to be a clear improvement on any previous product. To quote the design brief, the new product should stand out from the mass of high quality cassette decks.

In the tradition of Bang & Olufsen, one factor was taken for granted. To get the desired performance, improvements should be made primarily through elegance of engineering design, rather than primarily by the addition of the newest or the most expensive components. New components, whose value and effects on performance are still unproven by the test of time, are often an easy way out for the less competent product designer. They are also an advertising copywriter's dream because of the air of high technology such components give a product. But irrespective of the value of the new components to the consumer, the expense of developing the new technology is always reflected in the cost of the product. In top grade products of course, if new components are the only proven means to a significant improvement in performance, they should never be rejected because of cost. In most cases however, it is ingenuity in design that saves the consumer unnecessary expense, and forms the key to value for money.

Aesthetics are a way of life at Bang & Olufsen, where the ideas of the aesthetic designer are incorporated almost unconsciously into the product. And traditionally, ergonomics - man to machine communication - has been given high priority. Both are conceived early in the design stage, and incorporate materials, finishes and processes which have been consistent over many years. Because of this, it is possible to develop new shapes as an integral part of the engineering construction, so that the Bang & Olufsen box today forms only a minor fraction of the product cost.

All the more sophisticated cassette recorders have a large number of knobs, switches and preset screws which are not only user adjustable, but must be used to get optimum performance from the tape. These adjustments should be made every time a cassette is inserted, preferably using measuring instruments. Experience shows that few users, if any, are so dedicated as to go through the alignment procedure every time a cassette is inserted for recording or playback, or have the time and the instruments required to do so. Omitting the adjustments can result in larger deviations from optimum performance than that given by a machine accurately adjusted to mean conditions. In the race for better paper specification, the designers of such complex (to operate) machines have obviously forgotten that the idea behind the cassette was an easy to operate system.

Bang & Olufsen have always believed that one of the most important product parameters is the interaction or relationship between the machine and its user. It is therefore not surprising that a primary aim of the designers of the Beocord 8000 has been to produce a transport that is designed and optimised to require no mechanical adjustments together with electronics of the highest calibre, and to add a degree of "intelligence" which frees the user from boring chores. The result is a recorder that is amongst the easiest to operate, even though it cannot be faulted for having compromised sound quality. Even the complex facilities it offers are easy-to-use aids to a more complete use of the capabilities of the recorder.

The result of this project was the Beocord 8000, with a combination of performance sophistication and operational simplicity that stamps it clearly as originating in the laboratories of Bang & Olufsen.

Facilities:

The photograph, fig. 1, shows the layout of the primary and secondary control panels, as well as the display panel.

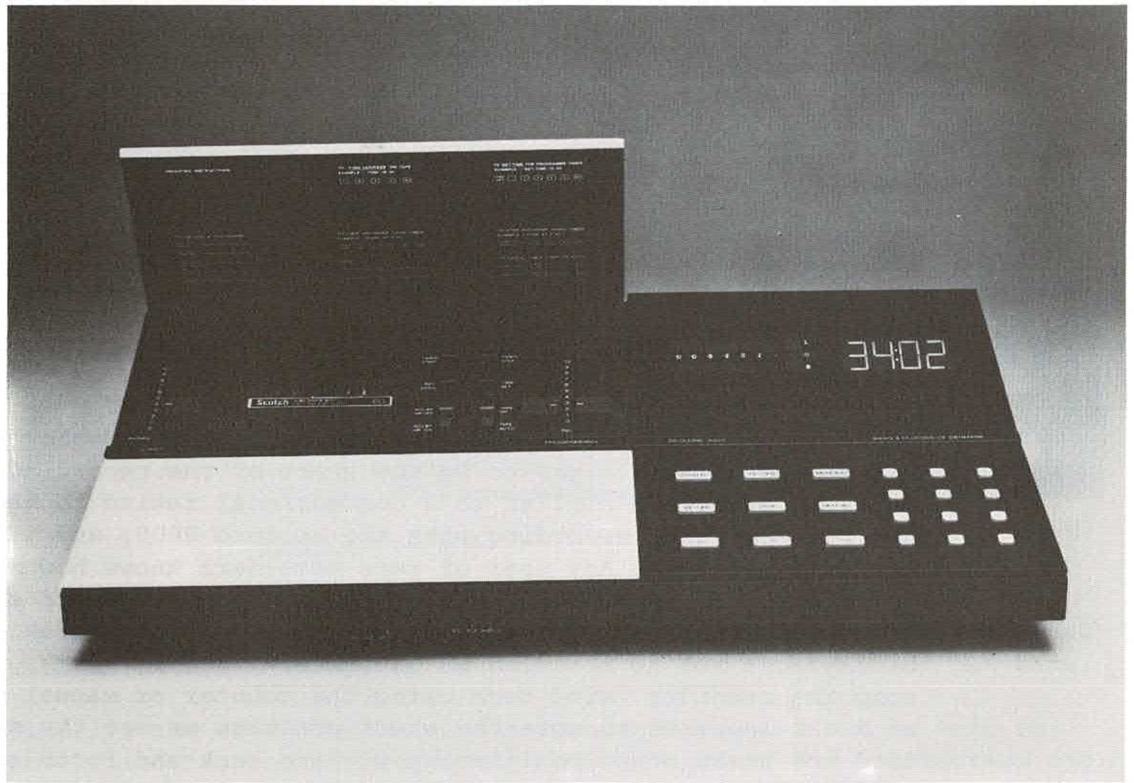

Fig. 1 - Beocord 8000

To avoid the confusion caused by a large number of knobs, buttons and switches, the control panel of the Beocord 8000 has been split into two. The primary panel has all the controls required during normal operation of the recorder. Controls not likely to be used frequently, as well as the recording safety lock, are placed under a hinged lid on a secondary panel. A display panel gives a continuous feedback to the user of the operations being carried out by the recorder.

All the normal features generally found in high quality cassette decks are included in the Beocord 8000, with detail refinements for better performance or for added convenience. But some unusual features have been added, and at least a couple that are unique among cassette recorders.

The opportunity offered by an electronically operated transport to give the user direct access to all functions has been taken to it logical consequences. For instance the Beocord 8000 has no conventional power on/off switch. When switched off, pressing any of the control buttons switches the recorder on automatically before it proceeds to carry out the instruction. And irrespective of its current operating mode, direct and safe access is available to any other operating mode at any time. Even switching the recorder off, or ejecting the cassette are direct access operations. The exception to this rule is the "record" mode, where most of the controls are locked, to prevent an inadvertent end to the recording. We call this "one touch operation".

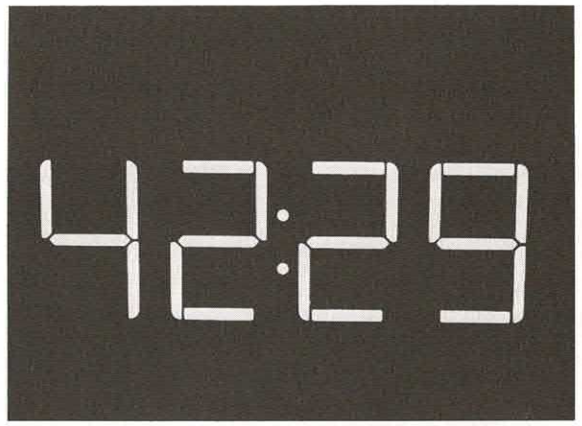

Fig. 2 - Tape position indicator

A unique feature of the Beocord 8000 is a tape position display in standard units of time, shown in the photograph, Fig 2. The tape position indicator performs a similar function to the three or four digit counters used on conventional recorders. But here the similarity ends. Instead of showing meaningless numbers, the counter on the Beocord 8000 actually displays tape position in minutes and seconds, units which are easily understood and meaningful to the user.

Another unique feature is a fully automatic memory which allows a direct and immediate return to the start of the recording being made. In principle similar to a conventional rewind to memory, it can be used while recording with the Beocord 8000, and is much easier to operate. Any user of tape recorders knows how many operations he has to go through if he wants to rerecord or erase that particular recording. The normal sequence of operations would be:
stop the recorder, wind back using the counter or manual memory if he has remembered to note the start position or set the memory, find the exact start position by winding back and forth and playing back, etc.

On the Beocord 8000, just press the "return" button directly from the record mode. The Beocord 8000 automatically rewinds to the start of the last recording, and is ready to record again. Nothing can be simpler.

A direct access search facility is included in the Beocord 8000, in conjunction with the tape position display. An exact tape position selector system is used in preference to the "track" finding systems seen on some new recorders, to allow the recorder not only to find the start of one of a number of tracks, but also any point within a track.

A manually set memory function is also available, and can be set or cancelled at will. The memory position is recorded as a time, and functions only on fast forward or rewind functions, but not during play, recording, or any of the automatic functions. There is a visual indication that the tape is winding towards the memory, and when it stops, the display indicates that it has stopped because of the memory.

In addition, the Beocord 8000 is capable of recording a programme without help from the user at the time the recording is made. A built in 24 hour clock, which works with mains accuracy, sets itself automatically to work with 50 or 60 Hz mains. A built in timer can be set to start and stop a recording at any given time within the next 24 hours. Needless to say, the timer can also be set to playback at a given time.

Fig. 3 - timer controls and display

A low voltage DC signal, available whenever the Beocord 8000 is switched on, allows an amplifier or tuner, used in conjunction with an external relay, to be switched on for recording or playback.

Finally, the Beocord 8000 will switch itself off if it is left to itself and has not performed any active function for 30 minutes, and switch off the DC supply to the external relay as well. This will happen for example 30 minutes after it stops at the end of a tape.

Real time tape counter:

The tape position display on the Beocord 8000 operates under computer control, in conjunction with a calibrating routine where various cassette and tape parameters are measured. A ring magnet with six pairs of poles attached to the take-up spool operating in conjunction with a Hall generator measures the rotation of the spools continuously. A microcomputer calculates the tape thickness, and other necessary parameters during calibration. The display then indicates elapsed time from the start of the tape, and functions in the recording and playback modes, as well as during fast forward or rewind, with all tapes and cassettes. In other words it is a tape position indicator in real time.

Calibration is erased every time a cassette is ejected, and a new calibration is therefore necessary each time a cassette is inserted. The calibrating routine operates automatically during normal recording or playback operations, and there is a visual indication to show that the tape is running uncalibrated. Even in this period the display shows minutes and seconds which are virtually accurate. After just over a minute, calibration is completed, and the display resets to read the accurate time elapsed from the point the tape was started.

Normally calibration is from the point the tape was started, which is not necessarily the beginning of the tape. Calibration from the beginning may be forced by pressing the button "GO". In this case the Beocord 8000 rewinds automatically to the beginning and calibrates the tape in a rapid process. It then rewinds to the original position of the tape before the process started. Normally it will then start a playback operation, but if the "GO" button is kept depressed for about two seconds during the instruction, the recorder will stop after rewinding. Calibration for the search function is always registered from the beginning of the tape, as described below.

Programme search and return:

The real time counter is not only a useful aid during recording, but in the Beocord 8000 also functions in conjunction with its search capability, and the button "GO". Just as in other recorders it is possible to watch the counter and wind to a known position on the tape, it is also possible to do so on the Beocord 8000, only automatically. The required number is punched in on the "calculator" keyboard shown in Fig. 4, after inserting the cassette. The Beocord 8000 will "calibrate" the cassette if it has not already done so, and find the desired point, without any further action from the user.

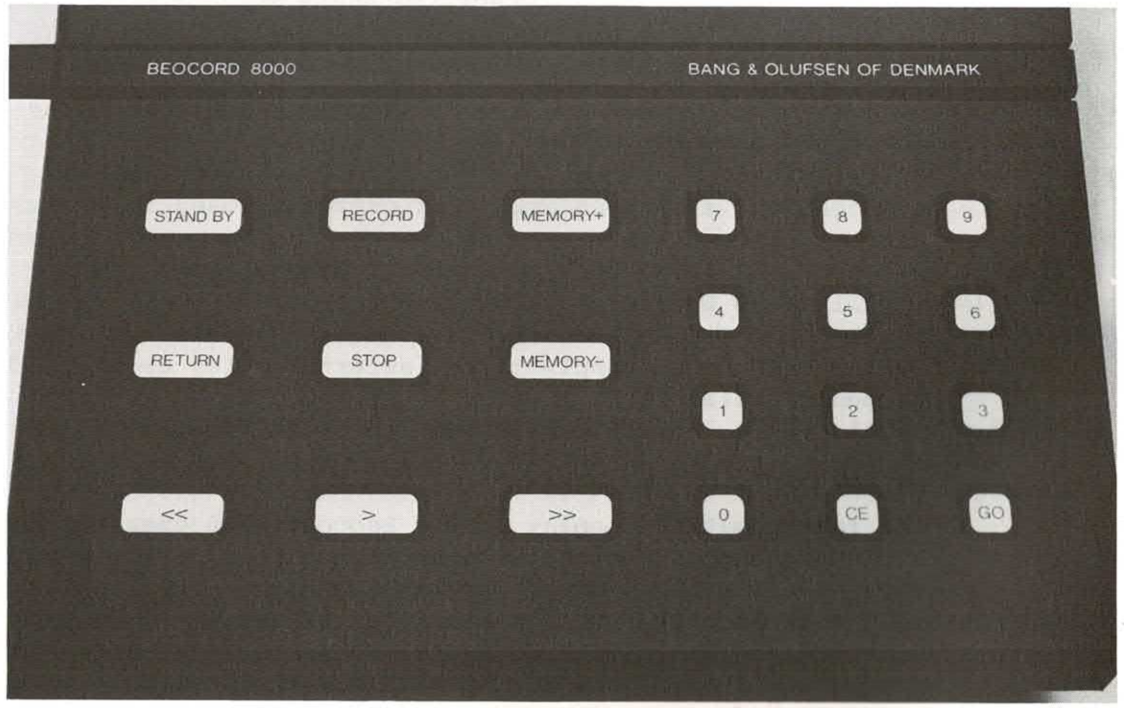

Fig. 4 - Keyboard

The search mode functions in conjunction with an automatic spacing feature which operates during recording. When a recording is stopped, the record amplifier is muted to prevent transient noise, but the erase amplifier and the tape transport continue for about 4 seconds. A space between the recorded tracks is created, which can be lengthened at will simply by keeping the stop button pressed.

After finding the approximate position as instructed, the recorder looks for this space and couples the playback amplifier to the output when the space is found, so that it can also effectively function as a track finding system. But it can be instructed to playback a recording or to stop, to allow manual switching to recording.

If one wishes to start playback from the middle of a track, the instruction to the recorder is the same, i.e. the tape position is punched in before pressing "GO". Since there is no space between two tracks, the recorder connects the replay amplifier exactly at the point instructed. This method may for instance be used to repeat a particular section of music directly from the keyboard.

The mechanism of the return function is basically the same. The start position is automatically memorised by the recorder every time the recording button is actuated. When the recorder receives a "RETURN" instruction, it stops the recording and rewinds to the position where the recording was started. It then monitors the space between recordings and stops the tape transport just before the start of the recording that has just been made. It then erases a very small portion of the tape before stopping again, so that any new recording made on the same section of the tape will not start with the unerased beginning of the earlier recording, and is then ready to record again.

Microcomputer control:

A lot has been written about microcomputers, and their apparent ability to solve all problems. It is perhaps superfluous to stress for anyone who cares to think about it, that while computers in general can be made to calculate and perform many different functions, it is the way it functions in a particular case that determines whether or not there is any advantage to the user. While its function partly depends on the capacity of the computer itself, it depends much more on the capacity of the programmer.

Ideally a computer used in an audio product should relieve the user of repetitive and logical chores without obstructing his creative freedom. Obstruction is avoided by making the computer easy to operate without the need for specialised knowledge.

Bang & Olufsen has taken a major step forward in furthering one of its best known design goals with the Beocord 8000, simplicity of operation. That microcomputer control has been used should not in itself bias judgement in either a positive or negative direction. Where a large number of operations require interactive control, a microcomputer can replace many mechanical and electrical switches with a single central "intelligent" unit. This is what has been done in the Beocord 8000.

But the intelligent use of a microcomputer does have other advantages for the user. Having introduced the microcomputer for reasons of cost effectiveness, it is logical to use any spare capacity for other purposes. The extra cost is negligible where spare capacity is used to provide easier control or additional features, as features are incorporated into the microcomputer program, and normally require only minor additions of components or of longer assembly time. But any features must give the user full, and if possible, added freedom to be creative. And normal operation, as well as the use of the special features should be logical and easy.

In the Beocord 8000, the microcomputer is used to control the logical functions in tape transport. If for instance from the fast forward mode the user presses play, the microcomputer ensures that all intermediate operations such as stopping the tape transport, moving the heads, etc., are performed as gently and quickly as possible, until the recorder is operating in the play mode. In addition, an illogical operation, such as pressing the record button without taking precautions against unwanted erasure of the tape sets off a visible "operation error" signal, and the order is ignored.

The primary control panel consists entirely of single pole push switches. All user instructions are communicated directly to the microcomputer, which is programed to operate logical functions in the correct sequence in the shortest time that the mechanical components allow. Many of the functions on the secondary panels are also switches of the same kind. This eliminates complex mechanical switches which are designed to perform mechanical and electrical switching simultaneously, and are expensive and unnecessary in the Beocord 8000.

Besides tape transport logic and error indication, all the items mentioned in "Facilities" are also under microprocessor control. The built-in clock, which can be set directly from the keyboard, as well as timer controlled recording (or playback) are a useful extension of the capability of the recorder. Features such as the ability to calculate tape thickness, which gives the Beocord 8000 the ability to indicate tape position in real time, would not be possible without the complex processing capability of a microcomputer.

The microcomputer used in the Beocord 8000 consists of the Intel 8049 8-bit computer, and an additional 8355 memory chip. The 8049 has 2 kbyte programme ROM and 128 byte RAM on one chip, while the 8355 chip provides an additional 2 Kbyte programme ROM, together with I/O facilities. The microcomputer operates at 8.867 MHz, for a 1.69 µs cycle.

Wow and Flutter:

In designing the cassette mechanism, or tape transport as it is also called, a decision had to be made even before actual design work started. For a number of years, detailed analysis of mechanisms had been carried out with sophisticated electronic tools, which had shown up the fundamental advantages and drawbacks of single and double capstan drives, on wow and flutter. The decision to be made was whether to further refine the double capstan drive of the Beocord 5000, or to try to develop a new mechanism with a single capstan.

Wow occurs mainly as a result of mechanical inaccuracies in the moving parts of the mechanism. An eccentric capstan in the transport chain, for example, will result in a cyclic variation in the speed with which the tape moves, at the same frequency as the rotation of the capstan.

Flutter on the other hand, has a different source. As the tape moves slowly past the head, changes in friction may cause the tape to "stick" momentarily to the heads, and as the tape is pulled further, to "slip" again. This stick-slip movement causes the tape itself to vibrate in a much higher frequency band than wow, and is called flutter.

In general, the more constant tape tension provided by double capstan machines results in low flutter, but comparatively higher wow, while the reverse is the case in single capstan machines, because they have fewer moving parts.

For the design of the Beocord 8000, analysis of the sources of wow and flutter were carried out using wide frequency band wow and flutter meters, together with sophisticated spectrum analysers to identify every individual source of cyclic speed variation. In the end, it was found to be more practical to refine the techniques to maintain constant tape tension at the heads in a single capstan transport, and thus ensure low flutter, than to design an even better double capstan system.

The Beocord 8000 combines the inherently low wow (the measured specification as well as audible changes in pitch) characteristic of single capstan machines, with extremely low stick-slip induced flutter, right up to frequencies of 1 KHz or more.

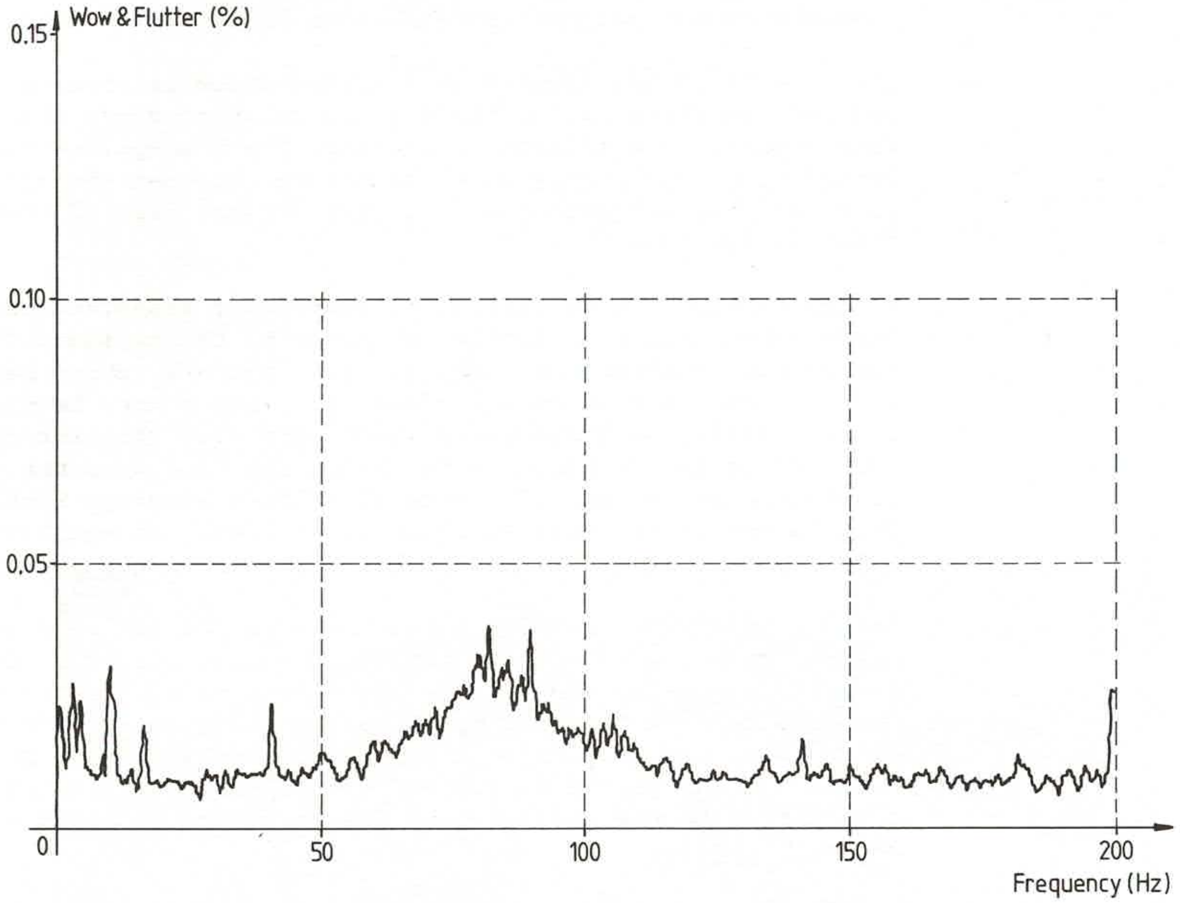

Fig. 5 - frequency distribution of wow and flutter

The cassette mechanism:

While in principle there can be very few differences in tape transports because of the standardised format of the tape cassette itself, detail design determines the performance potential, as well as the ease with which the product can be operated. And quality control during manufacture determines the performance level relative to its potential.

In the Beocord 8000, the tape transport is a refined design in which all mechanical functions are driven by electrically operated solenoids. This allows the tape transport to be a mechanically simple but highly sophisticated system, when external logic is added. External logic is of course provided by the microcomputer.

One of the major problems with solenoid operated systems is caused by the speed at which tape head assembly is pulled on to the cassette for the play or record modes. The shock generated as the assembly stops sets up vibrations which can damage the tape heads, the cassette tape or both. Complex systems are sometimes used to damp the movement, but these often prove unreliable. To remove the vibrations in the Beocord 8000, the solenoid core is designed to "float", and is radially damped by a rubber shock absorber.

To protect the tape heads against damage from the cassette holder, two safety systems are incorporated. The first is a microswitch which detects if a cassette has been correctly inserted, and allows the tape head bridge to move only if it is safe to do so. However, by manually depressing the microswitch, the heads can be made to move forward. In this case however, any attempt to lower the cassette holder triggers another microswitch, so that the heads move back. Thus, the most prevalent cause of head damage, contact between the cassette holder and the heads, cannot occur in the Beocord 8000.

The tape heads are mounted on a bridge which is steered in guides and runs on three balls. Three point mounting gives the bridge firm support, and eliminates rocking. The transport mechanism is itself mounted flexibly at three points, so that the vital moving parts are not subjected to tortional stress, even if the main frame is twisted.

A flat rubber belt of controlled compliance transfers rotational force from a tacho controlled DC motor to the capstan. To reduce the effect of other necessary drives, separate rubber belts connect the feed and take-up spools directly to the motor, leaving the capstan effectively decoupled. There are also friction clutches for the spools, to minimise forces on the tape when the transport is stopped at the end of a tape after fast winding. Such small details result in a system which is at least the equal of three-motor systems in performance, at a fraction of the price.

Another point that should be mentioned is the effort made to reduce mechanical noise. The motor itself is double shielded, and has a cap made of conducting rubber. The cap serves as a flexible suspension mount to prevent transfer of vibration to the transport or to the main frame, and thus reduces direct mechanical noise. The conducting rubber also stops the buildup of static electricity which can be transferred to the mechanism by the belt, and build up high voltages on metal parts.

Early in the design stage it was decided that the cassette transport assembly would be contracted to an outside supplier. A small manufacturer was selected, who maintained close contact with the design team throughout the design stage. With the help of our design experience the construction of the mechanism was detailed, and strict tolerance limits set and performance parameters agreed before starting. A fully automatic test panel for complete performance measurement, designed and built at Bang & Olufsen, was delivered

to the supplier, while an identical panel is used by incoming quality control at Bang & Olufsen to ensure that our quality standards are maintained. The tape transport mechanism is made exclusively for Bang & Olufsen, and will not be available in other products with the same format.

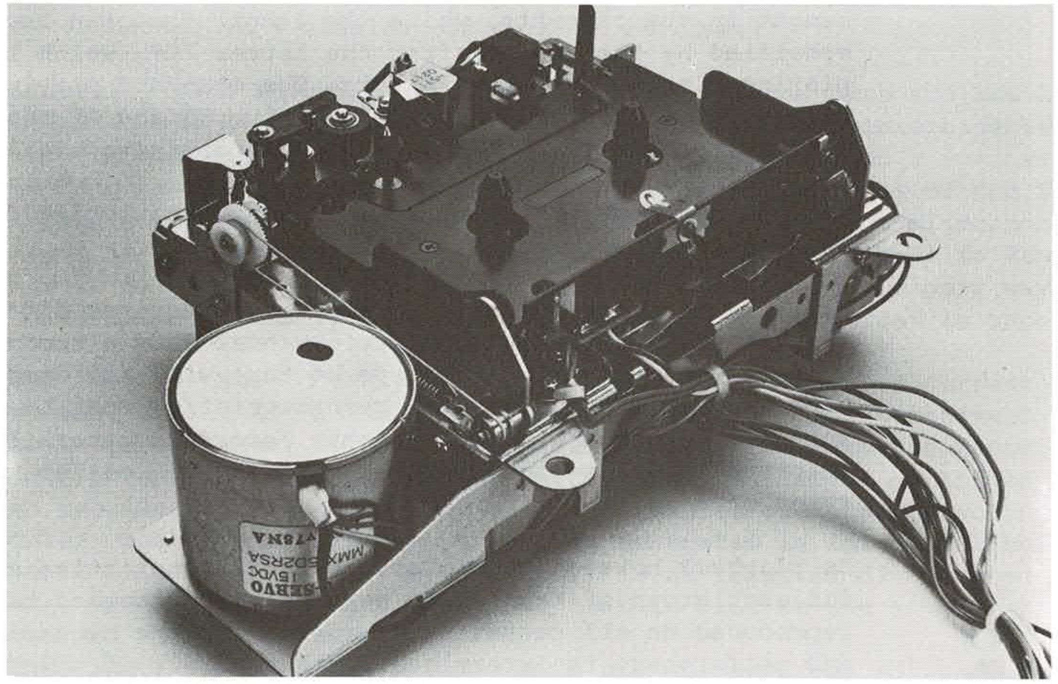

Fig. 6 - Photo of tape transport mechanism.

Cassette Tape:

Many types of tape are available for use in cassette decks today. They fall into one of the following broad categories of magnetic powder formulation.

Iron oxide
Iron oxide - low noise
Iron oxide - high energy
Coated iron oxide (chrome compatible)
Chrome dioxide
Ferro-chrome
Metal

Fig. 7 - Types of cassette tape

Besides the recognised branded tapes, a number of cassette tapes are available at extra low prices. These usually have variable characteristics and performance, often because they use tape rejected from the production lines of reputable manufacturers.

Another variable factor is playing time. This is a function of tape length in the cassette, while the length that can be packed is specified by the figure after the letter "C", which is the total playing time on both tape tracks. The standard playing times are 60 and 90 minutes (C-60 and C-90 giving 30 and 45 minutes on each side respectively), but C-46 and C-120 are also available. There is no inherent connection between the magnetic coating formulation and playing time, the combination being a marketing decision by the tape manufacturer.

Each of the above magnetic formulations requires different recording characteristics for optimum performance. Thus a recorder set to operate optimally with one type of tape will not operate ideally with another. The electrical characteristics must be readjusted to suit the tape being used. Cassette recorders generally have user operated manual switches or automatic selection for two or more types of tape.

On playback however, the electrical characteristics are standardised for each group of tapes. Any correctly prerecorded tape can be reproduced on all cassette recorders with the necessary switching, and performance is determined by the quality of the product alone.

While all cassette recorders can cope with all the variants of iron oxide tape, and those with a chrome switch adequately with chrome tape, a recent development in tape formulations sets new demands on the performance of machines. This is the new metal tape, based on pure iron powder as the magnetic material.

Metal tape has almost double the coercivity (the ability to retain magnetism) of chrome tape. Thus to use the tape to its limits, the recording amplifier must generate a considerably larger magnetic signal in the recording head than is possible with the conventional machine available today. Bias current must also be doubled to avoid distortion. All this requires more powerful electronics, and a recording head with a very high saturation level.

Problems also exist in erasing metal tape. Because of the higher coercivity, the erase signal must also be more powerful than for conventional tape. Also, because metal tapes have an inherently better signal/noise ratio than conventional iron oxide or chrome tapes, complete erasure requires the removal of an earlier recording to a greater degree than in existing machines.

In addition to the automatic switch (triggered by slots in the cassette itself) for chrome or ferric tape, the Beocord 8000 has a manual switch for metal tape, as no standard for coding metal tape cassettes exists today. In this position bias is altered, and other parameters set to that optimum for metal tape. The maximum output level (MOL) of metal tape is higher than conventional tape, and to use the extra headroom the signal to the recording head should be increased, so that the PPM indicators show +2 dB at peaks in the music instead of the normal 0 dB.

The Beocord 8000 is thus completely ready to make full use of the new high performance metal tapes, without any alterations, additions or adjustments.

The Signal Path - Recording:

Two signal input sockets are provided on the Beocord 8000. One of these can either be a high gain microphone input, or a line input, depending on the position of the input selector switch. The other input is part of a combined input-output socket, which may directly be connected to a similar socket on a receiver.

Generally when a common switched input is used for high and low level signals, the high level line input is attenuated to microphone level and the microphone amplifier used to boost the level to a nominal working level. This adds considerably to the noise level of the line input. A dedicated additional amplifier is used for the microphone input in the Beocord 8000, to step up the low level signal to line level. Although this adds to the cost, we feel it is the only way to do full justice to the standards of which the recorder is capable.

The selector switch in the Beocord 8000 is followed by a current to voltage amplifier, a characteristic of which is the exceptionally low noise level on any selected input. Instead of the normal compromise between sensivity and load, the "virtual ground" input amplifier has an impedance of 10 kohm. This allows 10 metres of interconnecting cable, and is unaffected by the noise generated in it. Signal/noise ratio below 1 µA at the input (10 mV) is at least 80 dB referred to 0 VU, with a frequency response that is flat to the 50 kHz rolloff.

The input amplifier is followed by a preset level control and user operable recording level slider controls, via a record/playback selector to a Dolby noise reduction circuit. The Dolby section uses the latest high accuracy integrated circuit, the LM 1011 A, for the closest matching to the standardised noise reduction equalisation curves. The processed signal is then fed to the recording amplifier.

The powerful recording amplifier, a development from our earlier models, excels in two respects. It has an output capacity that exceeds the electrical current requirements of the recording head by more than 6 dB, even for metal tapes. And it has an exceedingly low noise level. Its other characteristics, such as distortion, bandwith, ect., far exceed the capability of the cassette medium. The sensivity of metal tape is higher than standard tapes, and to compensate when the selector is switched to metal tape, the recording amplifier is attenuated by an amount so that the 0 dB on the peak programme always corresponds to the same absolute recorded level on the tape.

Finally, through an electronic switch (which shuts off any input signal to the combination head during playback) and a preset attenuator, the signal to be recorded is mixed with a bias signal. Three different bias levels can be set independently on the control module, and can thus be accurately preset to three tape types of the user's choice. The bias oscillator gets its information from the automatic or manual tape selection switches, the preset controls for the bias signal level and the record/playback selector switch. The Beocord 8000 is factory adjusted to metal, chrome dioxide and low noise ferric tape, as marked on the switches.

A passive multiplex filter is built into the recording circuit, to prevent beating with the bias frequency. It also prevents the Dolby noise reduction circuits from interpreting the pilot tone as a high frequency signal to be recorded, reducing the noise limiting action. If recorded, pilot tone frequencies are reproduced at a much lower level during playback, upsetting the Dolby equalisation networks, so that correct equalisation is not obtained.

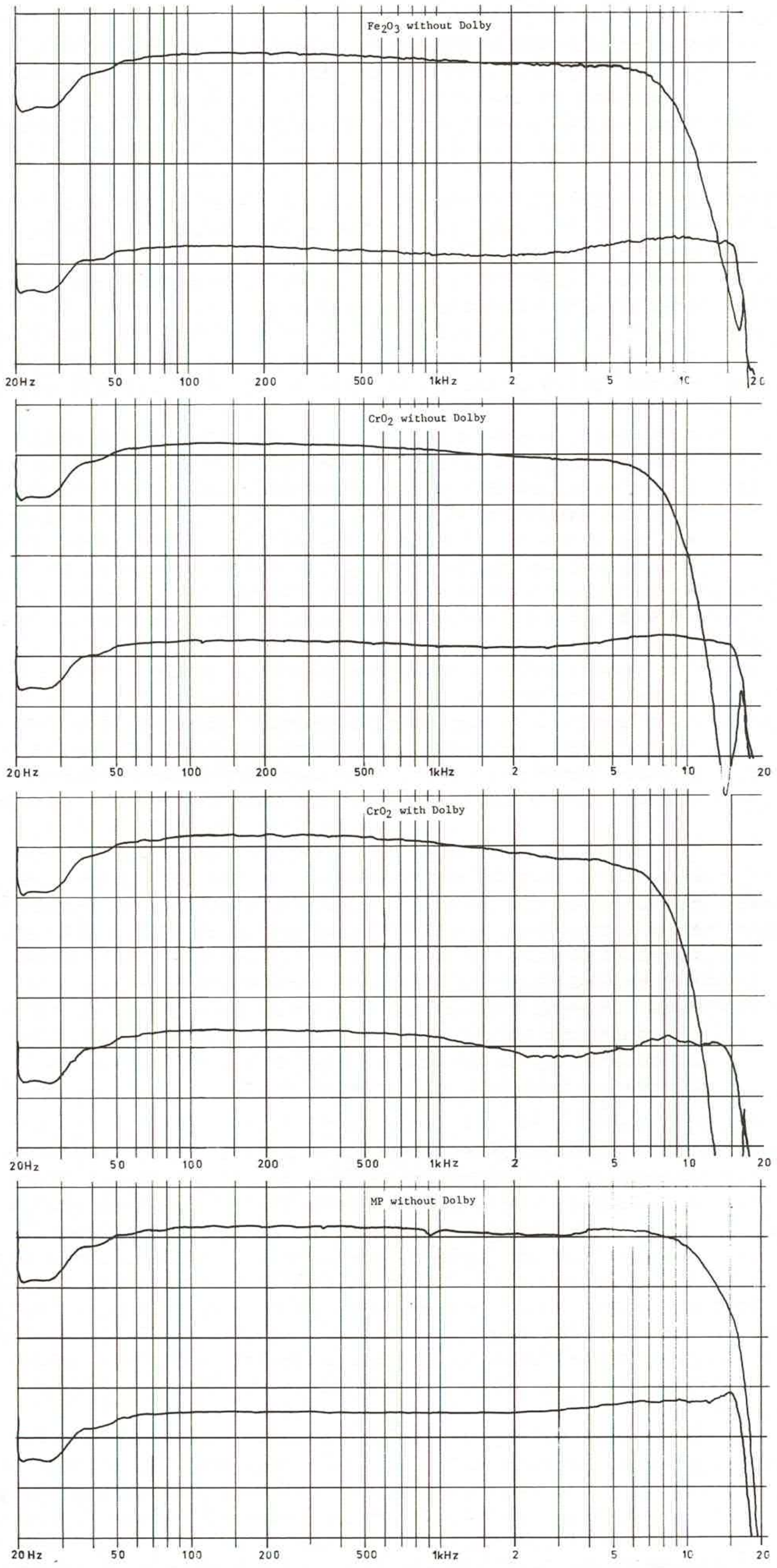

Fig. 8 - Record/Playback curves with oxide, crome and metal tape at Dolby level, and 20 dB below Dolby level. 5 db/division.

The Signal Path - Playback:

The playback amplifier is unusual for cassette recorders in that an extra amplifier stage is used as compared to conventional practice. Three stages of amplification are used, optimised for low internal noise, as well as perfect noise matching to the replay head. The first stage operates at very low collector current which is optimised to the characteristics of the tape head for a perfect noise match. The second stage also operates at low collector current, and acts as a buffer for the first stage, but also as a driver stage. Finally there is an output stage designed to give adequate output to any preamplifier, and may be preset to match the sensivity required. A separate headphone amplifier has an output adequate for both high and low impedance types of normal sensivity, and is operated through a slider volume control on the secondary control panel.

A ±15V split supply voltage is used for the playback amplifier, giving an overload margin of more than 40 dB above average signal level. This is more than adequate for present and for any future high output tape. In spite of this, the noise level of the amplifier is sufficiently low to be below that of any tape and noise reduction system that exists, or has been thought of.

Because the combination record/replay tape head of the Beocord 8000 has a gap width of only 1,5 micrometers, playback response extends to 15 kHz. Both the poles and the bedding surface of the head are made of Sendust alloy, with particular stress on the gap width and form, and strict quality control during manufacture. Sendust alloy is particularly suitable for the manufacture of tape heads, as its wear resistance is as high as any other head material, and its magnetic properties are in a class of its own at the very top.

Some head wear occurs during the first 300 hours use, which is a period of stabilisation. The resulting small change has been taken into account and the necessary correction preset at the factory. Due to the stress laid on uniformity in the gap width through the depth of the head, no further change in performance occurs even after 5,000 hours use. This is also due to the wear resistant Sendust alloy used for the head, which wears a minimal 4 micrometers after 1000 hours. The source of these figures is a research programme carried out at Bang & Olufsen on the wear of tape heads, some of the results from which were published in a paper read by Joergen Selmer Jensen to the Audio Engineering Society (AES). A reprint of the paper from the journal of the society is appended.

The highly polished contact surface of the head has a 5 mm radius to give best possible wraparound, which is the prime factor for tape contact. The radius is particularly satisfactory as little clogging of tape particles occurs, and the necessity for cleaning the tape heads is minimal.

The Peak Programme Meter (PPM):

The signal level monitor, a peak programme meter, consists of eight large LED indicators in each channel. The spacing of levels between the indicators is such that the smallest intervals are around 0 dB, to give the most accurate indication of peak recording level.

The meter circuit is unusual in measuring the current supplied to the tape head, rather than the voltage. The current is a more accurate indication of the utilization of the magnetic properties of the tape over the full audio bandwidth, rather than being just an indication of the signal level. The take-off point for the PPM, after the Dolby noise reduction circuits and preemphasis in the recording amplifier, accurately indicates the signal current being supplied via the recording head to the tape, rather than the signal being received at the input.

In addition, the characteristics of the meter follow professional practice, and are designed to standards specified by DIN 45406 for professional studio and broadcast recorders, with only minor changes to suit the cassette medium. Thus the full range of the meter is from -20 to +6 dB, instead of -50 to +5 dB as specified by DIN.

The response to a pulsed short duration signal meets the DIN standard exactly, with an indication of -4 dB after 3 ms. But without the inertia of the pointer in the LED display, response is slightly faster after 10 ms, 0 dB instead of the -1 dB specified.

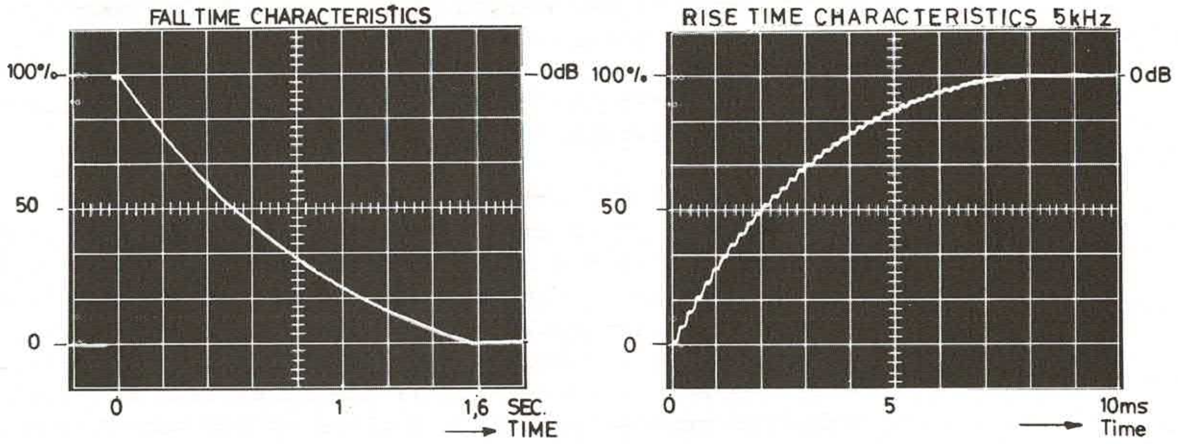

Fig. 9 - Rise time and decay curves for PPM

DIN also states that the peak should be indicated within 300 ms of the event, whereas the Beocord 8000 only takes 13 ms. And where DIN demands overshoot to be less than 1,5 dB, the overshoot on the Beocord 8000 is unmeasurably small.

A useful finesse is the use of a single comparator block after the A/D conversion in conjunction with multiplex display control, for the two stereo channels. The reason for this is to remove any differences there may be, or may develop in the sensitivities of the two channels. The displays thus always indicate exactly the same levels for the same input in either channel. In short, everything has been done to allow precise adjustment of recording level to extract every last bit of performance from the tape.

Levels are also monitored on playback, and the takeoff point is identical to that during recording. The peak indication will thus be identical on recording and playback, provided no compression etc. has occurred on the tape itself. Similarly, for prerecorded tapes, the peak level indicated is a measure of the maximum levels actually on the tape, with 0 dB peak indicating optimum recorded level for standard tapes, and +2 dB for metal tapes.

Demagnetisation:

Tape heads are liable to become magnetised, either due to switching transients, or by being exposed to permanent magnets. Magnetised heads lead to noise on playback, and can permanently damage a recording by superimposing background noise on an otherwise good recording. The unique demagnetisation circuits built into the Beocord 8000 ensure that the combination record replay head is always demagnetised.

Every time a recording is made, the demagnetisation circuit goes into operation. When the stop button is actuated at the end of a recording, the bias current is not switched off instantly, but progressively decreased to zero at a predetermined rate. Even though this occurs within a fraction of a second, the rate of decrease is controlled so as to create an effective demagnetisation current. In principle, the method is similar to conventional hand held demagnetisers, but is much more effective and completely automatic.

In fact the circuit is so effective that even if a head is deliberately subjected to a very powerful external magnetic field, no trace of magnetisation remains on the head after operating the RECORD-STOP sequence just a few times successively. This process is directly the opposite of other recorders, where performing the same sequence is likely to leave the head highly magnetised, and in need of processing with a hand held demagnetiser.

Erase amplifier and head:

To cope with the very high coercivity of metal tapes, powerful erase components have been used in the Beocord 8000. The erase head is made of ferrite, has twin magnetic gaps, and a very high current capacity.

The current capacity is indicated by the ability of the erase head to handle 160 mA before saturation, compared to about 80 mA for conventional heads. Together with a higher driving voltage from the erase amplifier, the erase circuit can handle almost 6 dB more power than conventional heads, besides being more efficient because of the twin gap construction. Powerful electronics are needed to drive the head, the power required being no less than 4 dB higher than for conventional machines for satisfactory performance with metal tape. The new erase amplifier in the Beocord 8000 has been designed for maximum efficiency. In fact the designers have been so successful in doing this, that no cooling fins are required, or

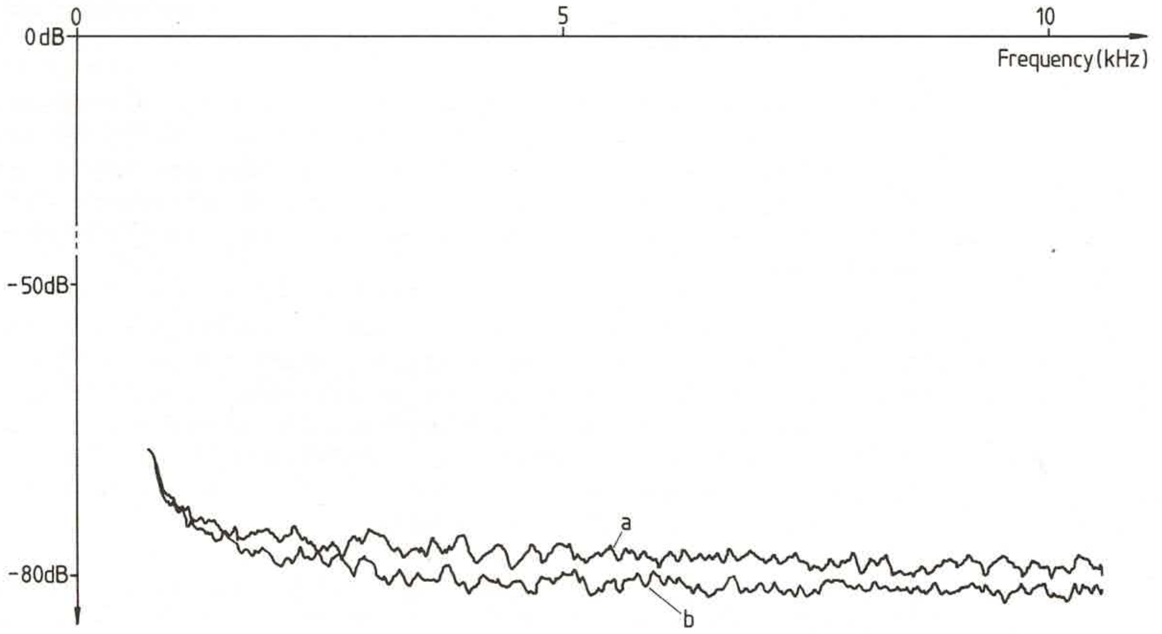

Fig. 10 - a. Spectrum of residual after erasure of white noise
b. Spectrum of noise in virgin tape.

used, to dissipate heat generated in the circuit. Fig. 10 shows the results of a single pass of the erase head in the recording mode, with the volume control at zero, on a broadband white noise signal recorded at +4 dB on metal tape.

The erase head is driven at 130 mA, 90 V and 96 kHz, giving it an adequate safely factor. Temperature rise in the head remains below 25^{o}C. Erasure of metal tape is typically 80 dB at 1 kHz, as shown in Fig. 11, which is the result of erasing a 1 kHz signal, recorded at a level of +4 db on the peak programme meter.

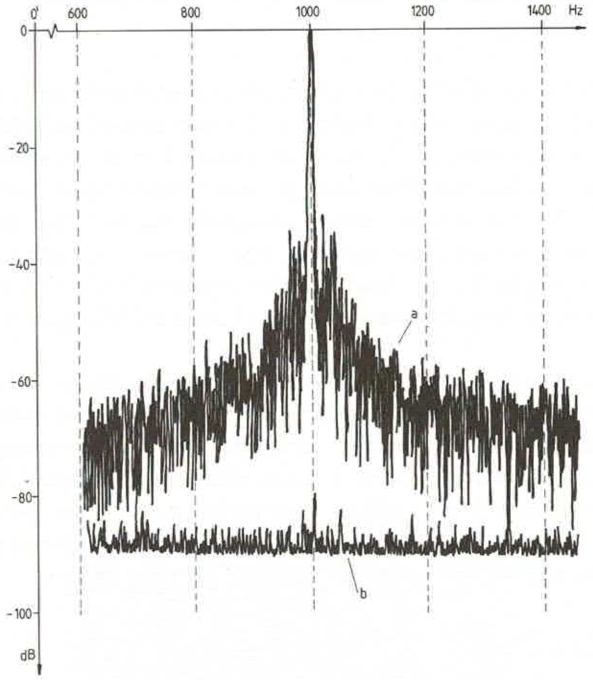

Fig. 11 - Erasure of 1 kHz.

In Service:

Should the Beocord 8000 require service, great care has been taken to make everything easily accessible, helped by a form of construction unique to Bang & Olufsen. The main chassis, as well as the base plate are single precision injection mouldings in rigid foamed polysterene. This permits all mounting brackets, screw holes, etc., to be made as a part of the chassis, with the resulting ease of assembly and removal for all internal components.

Internal partitions are an integral part of the moulding, supplying rigidity to the chassis. These partitions have built in slots and clamps for the circuit boards and screws are not required to hold them firmly in place. This allows easy insertion and removal of every printed circuit board in the recorder. All electrical connections between boards are made by flat cable connecting to sockets, adding to reliability and serviceability.

If it ever becomes necessary, changing belts on the cassette mechanism is simplicity itself. The base is removed by slackening four screws, and the removal of three screws holding a metal cover at the bottom of the mechanism gives direct access to the belts and to the capstan. Even changing the entire cabinet takes only a few minutes.

Another innovation is the transformer security package. For many good reasons including added safety, there is no voltage selector switch on the Beocord 8000. The transformer, together with the fuses are manufactured as a plug-in unit, to suit the electrical power available from the mains in different parts of the world. The entire cassette recorder operates from the safe low voltage secondary of the main transformer.

The Beocord 8000 has been designed for reliability. Samples of the recorder have been tested for resistance to heat, cold, humidity, shock, vibration and transport conditions, subjected to life tests and wear tests, to ensure a long and trouble free service life.

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Accurate Measurement of Tape-Head Wear Using Isotopes*

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A method for measuring wear on tape heads based on implanting a radioactive isotope in the gap region is described. By measuring radiation, rather than a mechanical parameter, an analysis of the wear pattern as a function of time is obtained, with an order of accuracy of 10% on a 300-hour scale.

The method allows indication of the transition from an initial wear period to the stable wear pattern. From such figures it is possible to predict the necessary period of use before stable tape-head-specification measurements may be made. Eight types of tape heads were measured, and the results are included.

0. INTRODUCTION

It is well known that mechanical wear sets a limit on the length of time a tape head may be used. What is less well known is the influence of various factors on tape-head wear. These may include the mechanical configuration of the tape deck, the geometry of the head itself, the kind of tape used, the tape speed, the relative humidity, etc. [1].

The factor generally considered most important to head life is the material of which the head is made. Head wear is loosely associated with material hardness, and it is assumed that the harder the material, the smaller will be the wear. Thus with the development of tape heads made of ferrite-based materials it was assumed that head wear had been reduced to an acceptable value [2]. However, the specification of tape-head life by product manufacturers, not to mention the guarantees of the tape-head manufacturers, leave much to be desired in terms of accuracy and can vary from the optimistic to the wildly pessimistic.

Cassette recorders present special problems with ferrite heads. Since the cassette was designed to use the same head for recording and replay, the low saturation point of ferrite sets a limit on the coercivity of tape usable with a common gap head. The problem arises when a head with a sufficiently narrow gap for adequate replay characteristics is used. On recording with the same head on chromium dioxide tape, ferrite material saturates before the particles on the tape.

New head materials to overcome these problems are appearing, and new tape coatings will continue to appear, together with new tape-transport mechanisms. The life of tape heads will continue to be a variable factor, and an accurate method for the measurement of wear is required to test not only the actual life, but also the pattern of wear during the usable period.

The usual method of measuring head wear is to allow tape to run in contact with the head in a jig. The head is then removed, and a profile measurement is made at suitable intervals. Besides the fact that the tape head cannot be replaced in an identical position for the continued test, inaccuracies are introduced owing to thermic or mechanical movements during measurement. Further, profile measurements are not capable of an accuracy better than 0.5 μm.

Inaccuracies are also introduced by the jig, which will normally not duplicate actual working conditions. The amount of tape pressure, wraparound, working temperature, etc., will not be the same as under normal use.

We can now begin to set up the requirements for an accurate measurement method.

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1. REQUIREMENTS

1) Tape heads must be tested in the tape transport mechanism in which they will be used.

2) The cassette mechanism, tape coating, etc., must be the same as that which will normally be used.

3) Measurement must be possible without removing the tape head or altering its position relative to the transport mechanism.

4) Wear measurement, with an accuracy of 10% of actual wear, must be possible within a few hundred hours of the start of the test.

2. TAPE-HEAD LIFE AND WEAR

The usable life of a tape head depends not only on the wear patterns of the head, but also on its geometry. In particular, the gap depth determines the point at which performance begins to deteriorate [3].

In this paper no attempt was made to correlate performance deterioration with head wear. The examples mentioned are solely to illustrate wear patterns of different materials under identical operating conditions, and should not be taken as absolute values of wear rates under different operating conditions, or of the usable life of any head.

3. DESCRIPTION OF EXPERIMENTAL TECHNIQUE

In determining wear, the use of radioactivity is often useful, especially when the amount of material removed by wear is measured in fractions of a micrometer. In the present study, where several materials of varying composition were tested, neither neutron activation nor the production of radioactivity by nuclear reaction were advantageous. Earlier experiments have shown neutron activation to give an accuracy of 0.25 μm at best [4], while in the case of nuclear reaction the whole sample becomes radioactive, making measurements of the wear on a small area of the sample impossible. Since the object of the investigation was to measure the wear properties only in the region of contact between the tape and the head, it was decided to label this area by ion implantation of radioactive atoms, so that by measuring the loss of radioactivity from the surface, the amount of material removed during operation of the tape recorder could be evaluated.

^{85}Kr was chosen as the radioactive tracer because it is an inert gas, which escapes when the material in which it is embedded is lost through wear. The half-life of ^{85}Kr (10.6 years) is sufficiently long to make corrections due to radioactive decay unnecessary, and the 110 femtojoule (fJ) (670 keV) gamma ray is easily detected by a 75-mm (3-inch) sodium-iodide crystal without removal of the head from the recorder mechanism.

Fig. 1 shows how a mixture of stable and unstable krypton isotopes was introduced into the ion source of the 10-fJ (60-keV) isotope separator at the University of Aarhus. The stable part of the mixture has an atomic weight of 84, while the atomic weight of the unstable part is 85. Due to the difference in their atomic weights, the two types of krypton separate and hit the screen at two points, the stable ^{84}Kr ions being collected in a Faraday cup (Fig. 1). The number of stable and unstable krypton ions reaching the screen can be calculated, as the voltage on the Faraday cup is known.

Due to the small target area (see Fig. 2), it was necessary to map the position of the tracer beam. The size of the target area (1 × 0.6 mm) was chosen to ensure that the radioactive area lay within the tape-contact area (Fig. 3).

Fig. 4 shows schematically how the stable beam of ^{84}Kr is directed into a Faraday cup while the radioactive beam hits a certain distance *a* away from the Faraday cup. A piece of aluminum foil was exposed to the radioactivity and afterwards placed on an X-ray film in order to measure the distance *a*. The mask (hole dimension 1 × 0.6 mm) was placed at a distance *a* away from the Faraday cup and exposed to the radioactive beam. Fig. 5 shows the spots on the X-ray film corresponding to the exposed area of the mask.

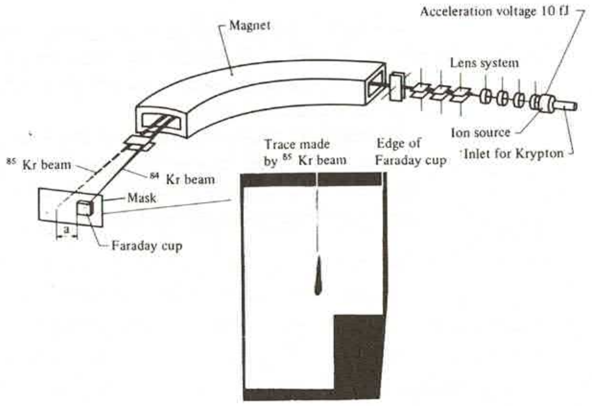

Fig. 1. Sketch of the isotope separator at the University of Aarhus. Inset shows spots on the X-ray film exposed to mask, used to measure distance *a*.

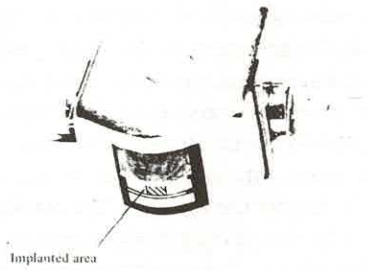

Fig. 2. Typical head used in the tests, showing implanted area.

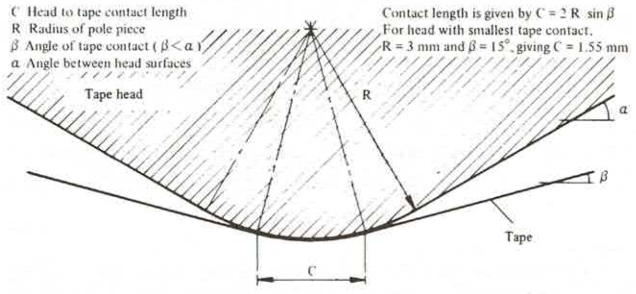

Fig. 3. Calculation of head-to-tape contact area.

Afterwards the tape heads were placed behind the mask, and radioactivity was implanted. Eight types of head (two samples of each type), representing materials commonly used in commercial heads, were investigated. A description of the heads is given in Table 1.

The tape heads were mounted in tape recorders, which were of a dual capstan closed-loop type, with wow and flutter unweighted peak to peak typically 0.15% on record-playback. The tape recorders were placed in an ambient temperature of 22°C and a relative humidity of 39%. The temperature rise at the surface of the head due to heat generated within the recorder was 15°C.

Commercial cassettes with chromium dioxide C90 tape from BASF were used at the standard tape speed of 47.6 mm/s. Cassettes were turned every 10 hours and changed every 20 hours. At regular intervals the cassette recorder was placed in a cabinet of lead shielding, with the gamma counter placed 190 mm away from the tape head (Fig. 6). The radioactivity remaining in the sample was measured as a function of the time of operation. Experimental results for the heads used are shown in Fig. 7, where the slope of the curves is a measure of the rate of wear of the surface.

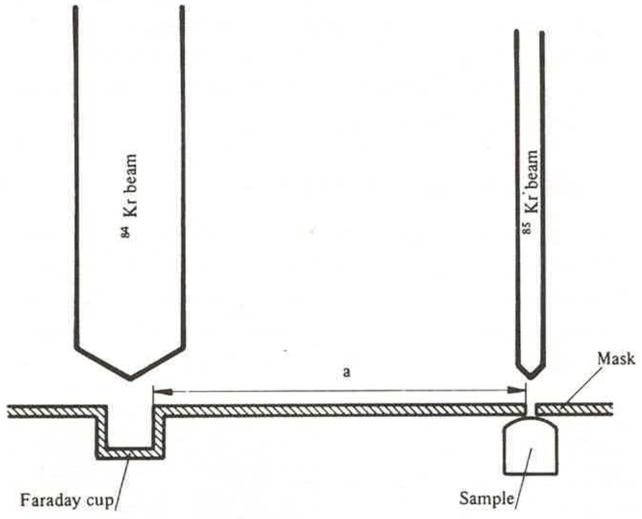

Fig. 4. Implantation of radioactivity on a sample.

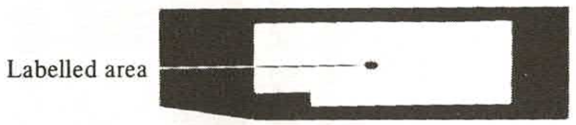

Fig. 5. X-ray film exposed to aluminum foil placed behind mask.

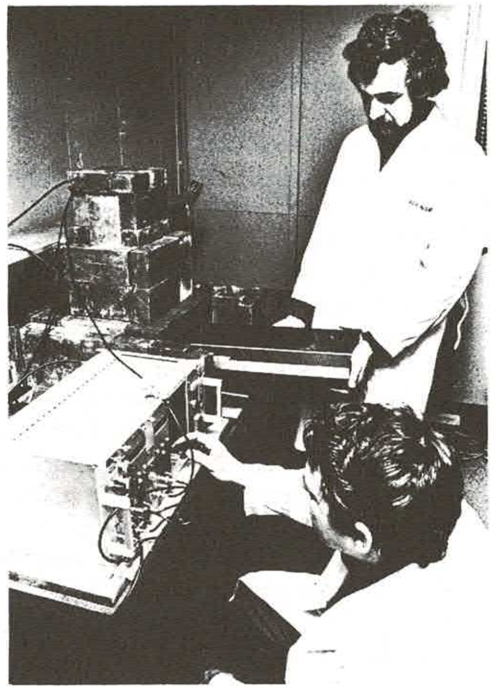

Fig. 6. Apparatus for measuring radiation. Cassette recorder is placed inside the lead cabinet for measurements.

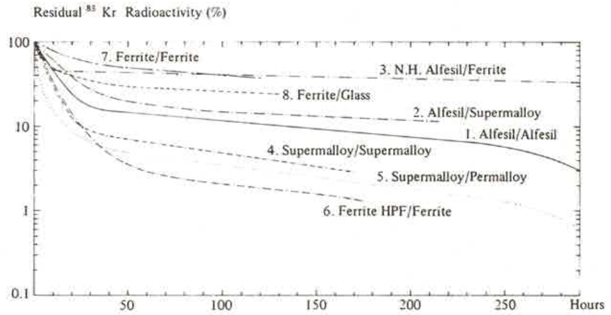

Fig. 7. Percentage residual radioactivity plotted against operating time for the heads listed in Table 1. Although all readings are corrected for background radiation, points plotted below 2% initial radioactivity are likely to have reduced accuracy.

Table 1. Types of head used in tests.

Number	Material	Track Material	Number of Laminations	Bedding Material	Contact Radius [mm]
1	Sendust	Alfesil	2	Alfesil	3
2	Sendust	Solid alfesil tip on laminated permalloy		Supermalloy	5
3	Sendust	Nitrite-hardened alfesil	3	Ferrite	3
4	Supermalloy	Supermalloy	4	Supermalloy	10
5	Supermalloy	Supermalloy	5	Permalloy	10
6	Ferrite	Ferrite HPF	Sintered	Ferrite	3
7	Ferrite	Ferrite	Sintered	Ferrite	10
8	Ferrite	Ferrite	Sintered	Glass crystal	5

4. EVALUATION OF DATA

The wear rate in micrometers per hour can be calculated if the penetration of 10 fJ ^{85}Kr ions in the various magnetic materials is known. The ranges of fast ions in solids can be calculated or measured experimentally. Since agreement between experiment and theory is usually satisfactory, theoretical estimates by Schiøtt *et al.* [5] have been used in the present study. The ranges of 10 fJ ^{85}Kr in supermalloy, alfesil, and ferrite have the ratios of 1.6:1.7:1.9, respectively, due to their elemental composition.

Fig. 8 shows the distribution pattern of embedded ^{85}Kr atoms in the head surface. In differential form this pattern assumes a Gaussian distribution, which leads to the integral range distribution shown in Fig. 9. In the present experiment, the radioactivity remaining after each test period was measured, and it was therefore appropriate to use the integral range curve as an indicator for the amount of material removed by wear. From theory the depth corresponding to the removal of 50% of the radioactivity can be evaluated. This depth is 20, 21, and 23 nm for supermalloy, alfesil, and ferrite, respectively. From the Gaussian distribution of Fig. 9 the depth beneath the surface was calculated for each measurement. The wear rate was then calculated for each time interval, and the results are shown in Fig. 10. The method of calculation allowed consistent wear data to be obtained.

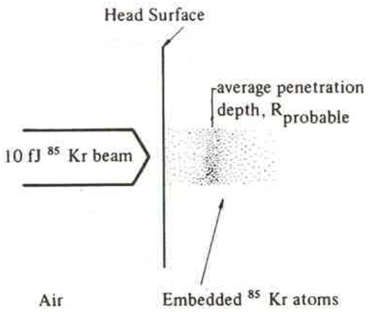

Fig. 8. Distribution of radioactivity in implanted heads.

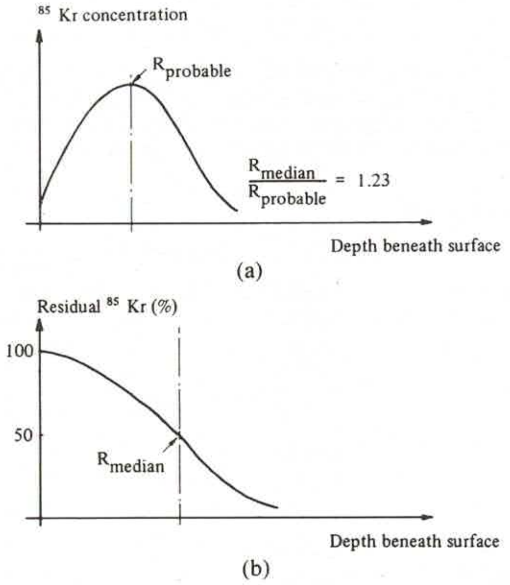

Fig. 9. (a) Gaussian distribution of ^{85}Kr atoms. (b) Integral range curve.

Two samples of each type of head were subjected to the wear tests. The small area (1 × 0.6 mm) exposed to the radioactive beam presented some difficulties, and therefore all samples were examined before the tests by covering them with X-ray film to verify that the correct area had been exposed to radioactivity. The example in Fig. 11 shows the distribution of radioactivity on the labeled area of a sample. Where small displacements from the correct position were found, discrepancies in the wear rate curves were observed when compared to the correctly labeled samples. Wear usually was faster in these cases, and this was taken into account when evaluating the data.

The labeling technique used is based on the assumption that embedded radioactive atoms do not diffuse, and that the wear is uniform over the labeled area. The data obtained show no sign of diffusion effects.

One of the problems encountered was that in spite of excellent lead shielding, background radioactivity was of the order of 2% of the initial radiation from the tape heads. In spite of corrections for background radiation for each measurement, the accuracy of the results decreases as the level of radioactivity remaining on the heads approaches the background level. This is particularly applicable for heads 4 and 5 (supermalloy) and head 6 (ferrite) because of their wear in the initial period.

5. DISCUSSION OF RESULTS

All samples tested showed a high initial wear period, followed by a decrease in the wear rate to a constant value. It is observed that supermalloy, alfesil, and ferrite show approximately the same initial wear rates, which decrease differently as shown. The nitrite-hardened alfesil shows higher initial wear than ferrite, but quickly drops to a much lower wear rate than the other samples.

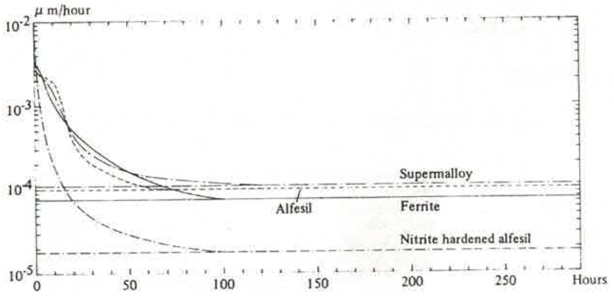

Fig. 10. Time dependence of wear rate. These curves give the average values of the slope for each material of Fig. 7.

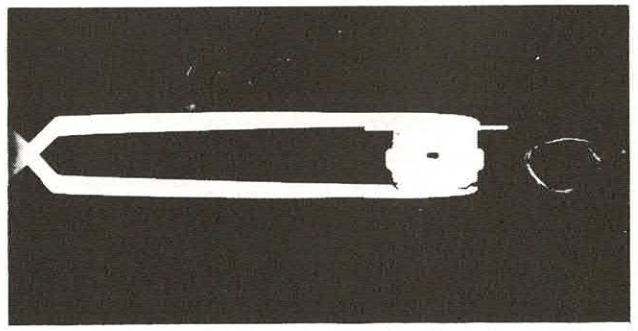

Fig. 11. Head exposed to X-ray film after implantation. Spot is the labeled radioactive area.

After 1300 hours of operation all the samples were measured, and wear was found to be consistent with the wear patterns measured after 300 hours of operation. Here only the nitrite-hardened alfesil heads still showed signs of radioactivity (27 and 16% for the two samples, see Fig. 12). These samples were placed on X-ray film, and the distribution of radioactivity was found. It was observed that maximum wear occurs at the leading contact edge of the tape and head. Thus wear properties derived from the present experiment must be considered average values over the labeled area (1.0 × 0.6 mm), but higher values may occur locally.

Fig. 13 shows the distribution of radioactivity on a ferrite head after 300 hours of testing. It is observed that in this case wear has been larger in the middle than in other parts of the labeled area. This effect was not observed on the nitrite-hardened alfesil heads, even after 1300 hours of testing. Fig. 14 shows profile measurements of a nitrite-hardened alfesil head after 300 and 1300 hours of testing. The nonuniform wear over the labeled area may account for some of the discrepancies between the method described and results from profile measurements.

Even though wear on the three ferrite samples differed in the beginning, they tended to exhibit the same slopes and hence the same wear rates after about 50 hours of operation. The same is the case for alfesil, but the steady wear rate is lower. Some of these differences are no doubt due to differences in head geometry, as are the differences in the distribution of wear over the labeled area reported above.

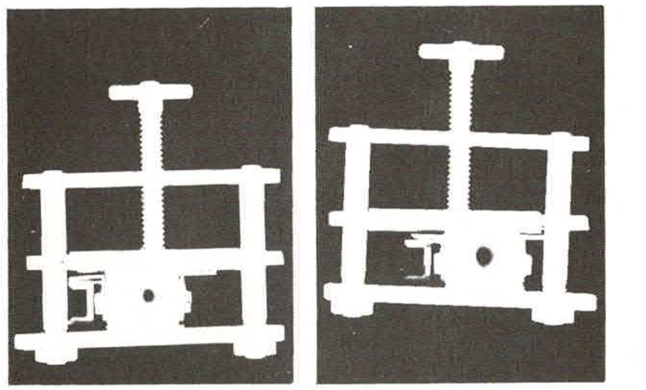

Fig. 12. Two samples of nitrite-hardened alfesil heads (no. 3) showing residual radioactivity as black spots; after 1300 hours.

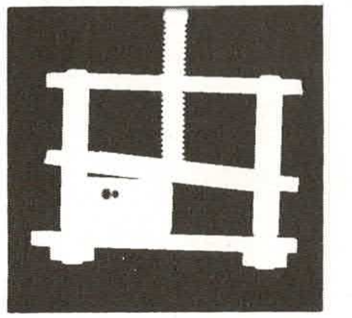

Fig. 13. Sample of ferrite head (no. 6) showing increased wear near gap (twin black spots); after 300 hours.

6. CONCLUSION

The pattern of wear in tape heads appears to be determined by a number of factors in a complex relationship. The results given in this paper are insufficient to map the wear of magnetic material on an absolute scale because of inaccuracies introduced by various tape-head geometries and the initial wear period. However, for identical tape-head geometries the labeling technique described is useful for estimating relative wear properties of different magnetic materials.

The method is considerably more useful in determining wear patterns of tape heads under actual conditions of use. This information is more relevant to both the tape recorder manufacturer and the consumer than the absolute wear-rate values of magnetic materials. Acceptable results are available after a test period of only a few hundred hours, both of the initial wear pattern and of the steady-state wear rate.

7. ACKNOWLEDGMENT

The author would like to thank Dr. G. Sørensen of the Fysisk Institut, Aarhus Universitet, for his help on the theoretical aspects and the implementation of ion implantation, and for undertaking the calculations on wear. C. Bagger of the Forsøgsanlaeg, RISØ, was responsible for

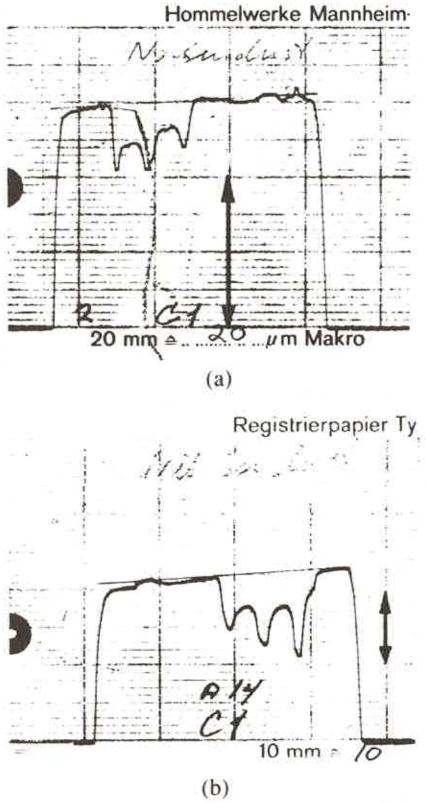

Fig. 14. Profile measurements of a nitrite-hardened alfesil head. (a) After 300 hours. (b) After 1300 hours. The diagrams are virtually identical (although mirror images). Vertical scale 1 μm/mm.

the design and implementation of the measurement method and equipment. The actual measurements described were carried out by Flemming Jacobsen under the capable guidance of Valter Loll, both of Bang & Olufsen.

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After his compulsory military service in the Danish Air Force he joined Bang & Olufsen a/s in 1972. He has since worked in the tape projects group and is at present responsible for all components connected with audio-signal paths in the tape medium. He is a member of Ingeniør Sammenslutningen and the Audio Engineering Society.