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Advances in helical video tape recorders for television broadcasting

Summary

This article is the first of a series on video tape recording and deals with the MR1 helical scan recorder being introduced by Marconi Communication Systems Limited. The MR1 and the MR10 portable version are equivalent to the Ampex VPR-1 and VPR-10, and are to be manufactured by Marconi by agreement with the Ampex Corporation.

The quadruplex type of video tape recorder has dominated the broadcast television field since its introduction in 1956. However, there has been a demand from broadcasters for a smaller, less expensive recorder having nevertheless the standard of performance necessary for broadcast television. This demand is met by the MR1 which also provides additional facilities such as still-frame and slow-motion replay, needed in present day programme production and editing practice. Being a non-segmented machine, the MR1 is entirely free of head-banding defects which can occur in quadruplex or segmented helical recorders.

The entirely new and robust transport design in the MR1 has eliminated problems of earlier helical machines, especially when used with the MTBC1 digital time-base corrector and AST, automatic scan tracking.*

Introduction

The role of the video recorder in television broadcasting assumes greater importance year by year. Over half the BBC network output is from video tape, and for CBS in the U.S.A a figure of 70% has been quoted.[1,2] The original function of the video tape recorder (v.t.r) of providing for a repeat or a later transmission of programmes now accounts for a small fraction of usage, and it is in programme assembly and editing that expansion is most rapid.

This article is the first of a series dealing with video tape recording, and follows the entry of Marconi Communication Systems Limited into this field. We shall describe in particular the design and operation of the new Marconi MR1, a 1-inch helical video tape recorder, and also the MR10, which is a compatible portable version. These recorders are equivalent to the Ampex VPR-1 and VPR-10 respectively, and are to be manufactured by Marconi under an agreement with the Ampex Corporation reported elsewhere in this issue. While satisfying the demand for a smaller, more economical type of machine of broadcast quality, these new helical v.t.rs also provide a number of new features in line with current trends in television production.

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After discussing further the characteristics required in a new recorder the author goes on to review some of the history of videotape recording relating to the helical principle, since in retrospect it is remarkable that the lower cost helical scanning machine did not appear much earlier than it did as at least a major, or even the principal type of broadcast television recorder. Some hitherto characteristic problems of helical scan are then discussed, and how they have been eliminated in the design of the entirely new type of transport of the MR1.

Further articles will deal in greater detail with the design and operation of the MR1 and MR10, and also the MTBC1 digital time base corrector, equivalent to the Ampex TBC-1. New editing equipment will also be described in a later article.

The need for a new type of video tape recorder

For some time there has been a need felt in many broadcasting organizations for a smaller type of video tape recorder, less expensive in terms of capital investment and operation and maintenance costs, but having the level of performance necessary for general use in television broadcasting. The requirements were expressed in detail in an EBU statement,[3] and SMTPE committees have been working towards a similar objective. In addition to the desire for a more economical machine, there is growing concern over the space required for archival storage of taped programmes, and here a recording format employing a smaller volume of tape per hour would clearly be helpful. In 1976 the BBC alone had 36,000 Quad I tapes in its libraries.[1]

In adopting a new format at a time when EFP, electronic field production, is developing rapidly, it would be essential for a lightweight portable type of recorder using the same format to be available. Another factor in general programme production, as well as in EFP, is the increasing use of film type techniques with video tape recordings, involving much more post production editing. It would be a great advantage, if not essential, for any new machine to embody convenient and flexible editing facilities.

There would seem to be little prospect that the objectives might be achieved through modifications to the quadruplex machine, and Todorović, in an interesting review of the current situation in television recording,[4] refers to the Quad I standard as being 'somewhat exhausted'. He acknowledges the improvements offered by the proposed Quad II standard, but goes on to repeat the need for a smaller and cheaper recorder. As

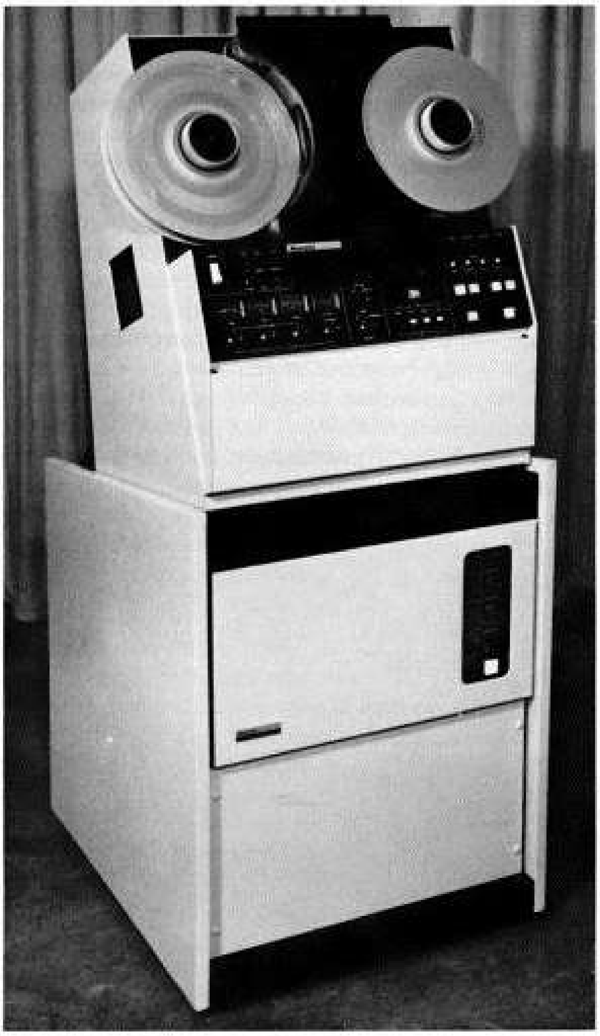


Figure 1. The Marconi MR1 non-segmented helical video tape recorder, with the MTBC1 time base corrector fitted beneath

possible alternatives to quadruplex there are only the longitudinal and helical scan formats. Longitudinal recording was investigated by a number of organizations, prior to the introduction of the quadruplex machine,[5] but was rejected because the very high tape speed necessary led to impractically large reel diameters, and made it impossible to shuttle fast enough. Thus it was assumed that the need would be satisfied by a new type of helical-scan machine. This has proved to be the case with the introduction of the MR1, (figure 1), which together with the MR10, provide all the features required.

Some historical notes

Even before the introduction of the quadruplex v.t.r by Ampex in 1956 the advantages of the helical-scan system had been recognized, being basically simple and offering low operating costs, especially when designed on a non-segmented, field-per-scan basis, which also made still-frame or slow-motion replay possible. In the U.S.A at this time there was, however, an urgent need for a television recording method to delay east coast programmes for transmission on the west coast so as to compensate for the time difference.[6] Consequently, because there were serious problems yet to be solved in the helical format, it was decided that the fastest way to develop a broadcast quality recorder was for the Ampex team to concentrate on the transverse format.[7] This was done, and led to the historic demonstration in April 1956 of the first practical video recorder.

A momentum generated by the rapid expansion of television operations carried the quadruplex standard forward, so that there was little chance of acceptance of any new non-compatible recording format. There were helical recorders subsequently developed, intended for broadcast use, including one by Ampex,[5] but for one reason or another they made little or no impact.

The quadruplex format went on to become, by national and then international standardization, the principal medium of video programme exchange and distribution. Well in excess of 10,000 quadruplex video tape recorders are in use, to be found in every country of the world.

Taking a detached view one can see the helical scan as an engineering concept no less worthy than the transverse quadruplex, and actually offering more in operational facilities. Quadruplex had the great virtue that it could be made to work, at a time of great expansion in television broadcasting, when a more convenient alternative to film recording was badly needed.

Advantages of the non-segmented helical video tape recorder

An important advantage of the non-segmented helical principle is its basic simplicity. It permits the design of video tape recorders that are small, inexpensive and low in running costs. Since one head records or replays a complete active field there is not the need to switch between heads, nor to match heads and signal channels closely in the factory or in the field, as there is in the multi-headed quadruplex or segmented helical formats.

Probably the most significant advantage the non-segmented helical scan system has over both quadruplex and segmented-helical is the complete elimination of head banding, or segmentation errors. In many, if not most cases, it is the accumulation of segmentation errors that limits the number of generations achievable in quadruplex recording.

In terms of operational functions the availability of still-frame and slow-motion are noteworthy advantages of the non-segmented helical system, either as broadcastable effects or as valuable adjuncts in editing.

Early helical problems

The problems in the non-segmented helical scan system, mentioned above, were two-fold: poor time-base stability and poor tracking accuracy, both functions of the quality of tape transportation and guiding. Both arise from the long track necessary (about 43cm; 17in), in the helical wrap around the scanner drum, to achieve a high enough writing speed. The track width is 0.15mm (0.006in), and the tracks lie at an angle of just over 2°. The figures are typical and relate to the well-established Ampex 1-in format.

TIME-BASE STABILITY

Because the recorded tracks lie substantially along the direction of tape motion, any variations in tape speed are translated almost directly into variations in timing of the reproduced signal. A partial solution came with the development of electronic time-base correctors to reduce the rather lesser instability of the quadruplex machine. However, these early analogue correctors, employing a voltage-controlled delay line, had a limited range which imposed severe requirements on the transport servos of the helical machine, so this solution was not completely sucessful, a very high order of time-base stability being necessary in broadcasting.

TRACKING ACCURACY

It is not surprising, considering the track dimensions quoted above, that it was also difficult to make the tape take the same path relative to the head on replay as it took on record.

It is understandable that 'interchange confidence' was lacking, the confidence in the ability to interchange tapes between different machines. On early helicals satisfactory replay on the same machine at a later date was by no means certain.

Among the perhaps less obvious factors contributing to tracking errors were the insufficient stiffness of the transport chassis, and the critical significance of the precise form and frictional properties of the tape guides. Of particular importance are the entrance and exit guides by which the tape is led on and off the scanner drum, because between these the tape is supported only on an air film.

A major contribution to the tracking problem was in the dimensional variations in the tape itself caused by temperature, humidity, ageing, manufacturing tolerance or physical damage. While there have been great advances in the quality of tape over the years, it is still necessary in the design of video tape recorders for broadcast use to make some provision for abnormal tape variations.

Figure 2. Transport deck of the MR1 video tape recorder

As we shall see, the solution of the problems described has been achieved in the VPR-1 v.t.r by methodical investigation of the causes and their elimination by good engineering, plus some innovative steps.

THE SEGMENTED HELICAL APPROACH

The segmented-scan helical machine represents another approach in which the problems are eased by employing two active heads typically, the scan being split into five or six segments per field. Thus the recorded tracks become shorter and lie at a larger angle to the tape edge. However, by this course one abandons many of the advantages of the non-segmented helical format, including still-frame and slow-motion direct from the machine, and the likelihood of segmentation errors, that is, head banding, is reintroduced.

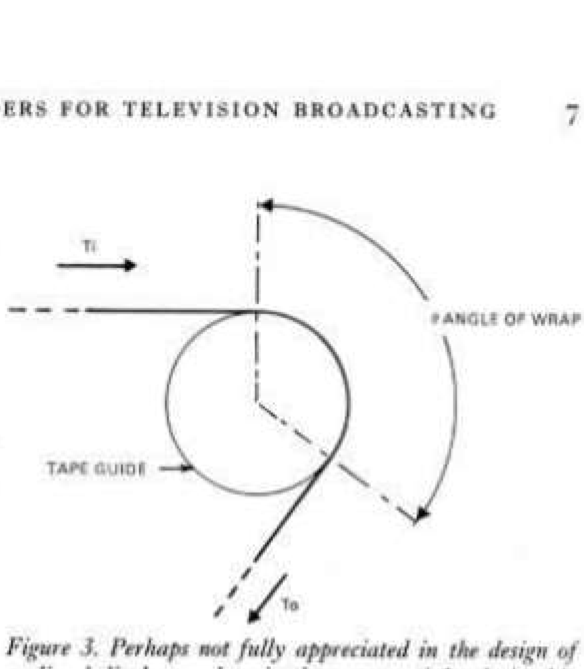


Figure 3. Perhaps not fully appreciated in the design of earlier helical recorders is the exponential relationship between tape tension and the angle of wrap (θ) and coefficient of friction (μ)

Design of the VPR-1

Although for professional broadcast applications Ampex engineers have concentrated on the quadruplex machine, they have over the years designed a number of very successful helical recorders aimed principally at the educational, industrial and other c.c.t.v fields where very large numbers are now in service. Some of these have been in fact employed for broadcasting where conditions were favourable, the VR-660 for example, was used for many years by the Canadian Broadcasting Corporation to distribute programmes to small stations in the north of Canada. Of course, many helical machines are used by broadcasters for non-broadcast applications, particularly for off-line editing, for rehearsals and in various other c.c.t.v roles.

It is significant, with this substantial experience in both helical scan and quadruplex systems, that Ampex have returned to the field-per-scan helical principle in this first major departure from the quadruplex format in a broadcast quality v.t.r.

The transport

As we have seen, the problems of the format stem largely from mechanical factors, thus the design of the VPR-1 started with the construction of a substantial transport (figure 2) of very high precision. It employed the established Ampex 1-in tape format. To quote Anderson[7] 'this effort alone yielded vast improvements and a recorder of outstanding stability.' While the maximum utility, flexibility and ultimate performance are achieved with the aid of the digital time-base corrector, the TBC-1, and the automatic scan tracking system, AST*, the basic VPR-1 is itself an excellent low cost professional quality machine.

The problems that had to be solved, time base instability and tracking inaccuracy, both involve the transportation and guiding of the tape.

Considerable time and effort was therefore spent in studying the behaviour of tape while being guided, and the head-to-tape interfaces, in the various operating modes and under various environmental conditions. This work pointed the way to the detailed design of the transport, a lucid account of which is given by Hathaway and Ravizza.[8]

TAPE GUIDING

Referring to the failure of early helical v.t.rs to handle tape adequately, Anderson[7] commented that the engineers had failed to understand how tape tension increases exponentially when tape is wrapped around a stationary guide (figure 3). It is related in fact by the formula $T_o/T_i = E^{\mu\theta}$, where μ is the coefficient of friction and θ the angle of contact. The amount it is wrapped must be minimized, and rotating guides used if necessary. This serves to illuminate clearly the tape handling defects of the early helicals when it is realized that the coefficient of friction varies significantly with temperature and humidity, from one type of tape to another, and with tape age. One can see how the load on the capstan and the stretching of the tape will vary. At least as important is the deflection of the tape line of motion with change in μ owing to the angle of wrap being different at one tape edge, from that at the other, which can occur if the tape is forced to twist. The difference in wrap angle may also be due to misalignment of cylindrical guides, or actually to the use of conical guides fitted in early designs. These differences obviously have the most serious effect on tracking when they occur at the scanner entrance and exit. Tape guiding in the VPR-1 is based on the concept of the 'natural' tape path, and no guides contoured to force the tape into position are used.

The angular adjustment of the scanner entrance and exit guides in the VPR-1 is intended to compensate for production tolerances (rather than to produce bias and hence stress) so that they can be set in the ideal position, allowing a natural tape flow. There are no routine mechanical adjustments necessary in service to ensure the ability to interchange tapes.

Edge guides within the audio and video head areas are made from highly polished ceramic material so that

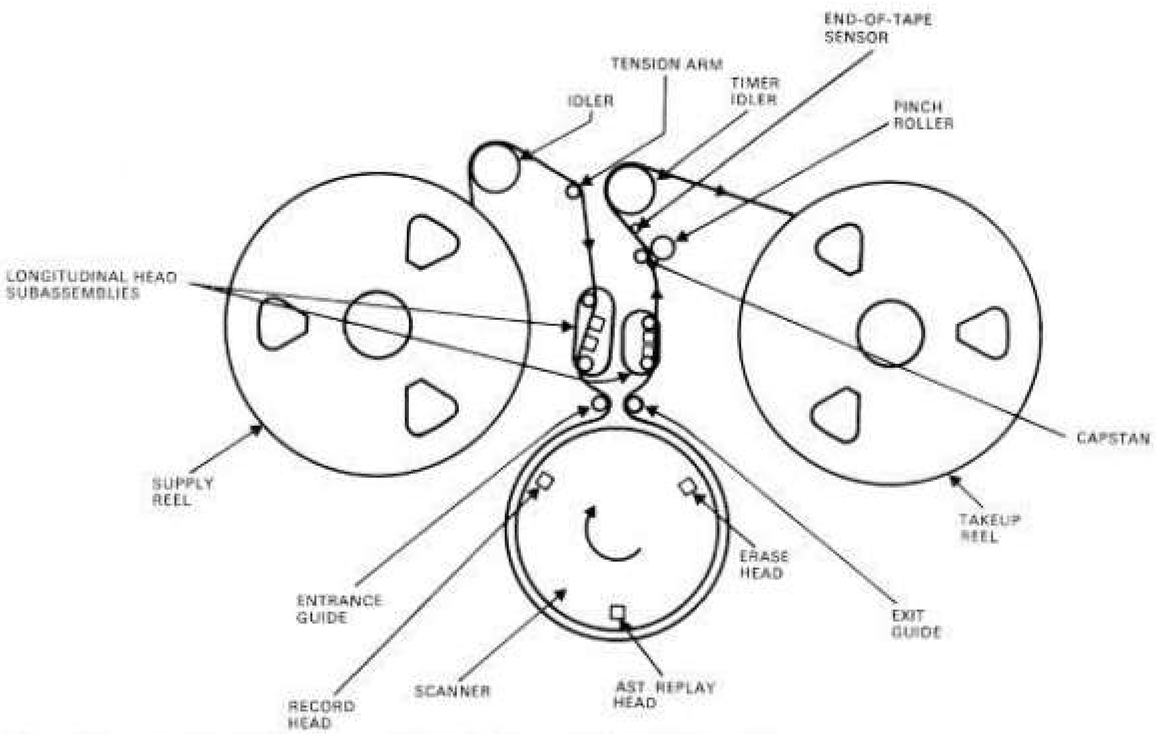


Figure 4. Layout of the MR1 transport illustrating the straightforward tape path

the tape flow is permanently established. Stability of the guiding elements is ensured by their substantial construction and attachment to the base casting (figure 5). No movable guides are employed since these were in part responsible for interchange problems in earlier machines.

Excessive friction between the tape and the various surfaces it contacts will cause serious problems in a helical recorder. For the VPR-1 careful studies of surface finishes and coating were made in order to determine the optimum treatment for each surface. In the case of the audio and control track heads, for example, the entire contacting surfaces are coated with carbon particles by an impingement process. This not only reduces wear but also prevents the surfaces from becoming highly polished, which causes stick-slip problems. For each tape guide also the optimum finish was selected in relation to its angle of wrap and tape tension.

CAPSTAN

The design of the capstan system is of course of prime importance in achieving a uniform tape speed.

The surface of the capstan must have a long life and provide a reliable and positive tape drive despite changes in tension and in environmental conditions. In an extensive testing programme many surface finishes and treatments were investigated, and it was found that a ceramic-coated surface provided better characteristics than the plain stainless steel capstan used in most recorders. The associated pinch roller is equally important, and a similar comprehensive programme of investigation was embarked on to find the optimum configuration.

The capstan drive is from a fully-servoed d.c motor, and in the interest of gentle tape handling, the rate of acceleration on start-up is automatically controlled.

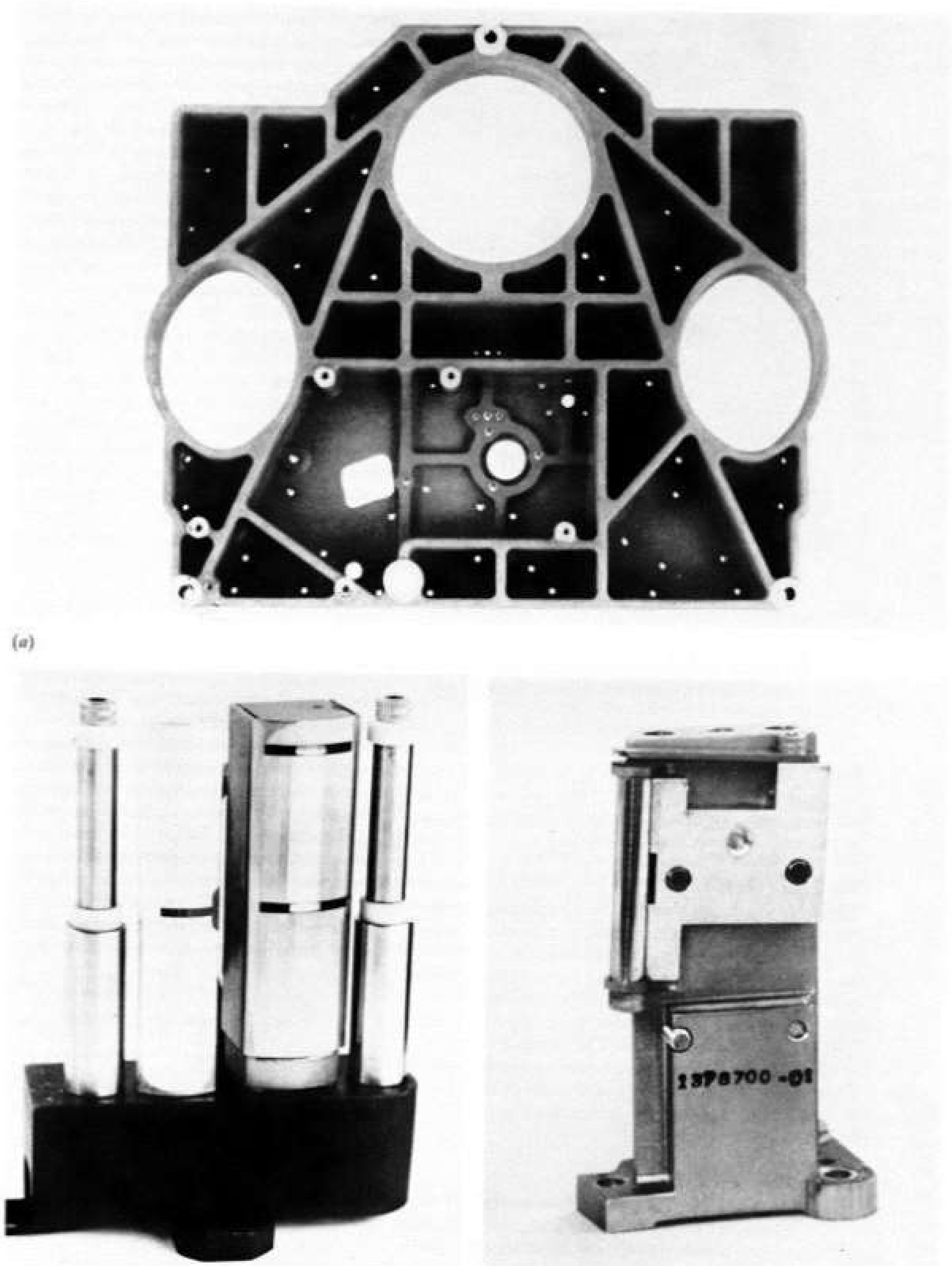
REEL DRIVES

Both the supply reel and take-up reel employ d.c motors driving the reels directly (figure 6). They are fully servoed so as to provide constant tape tension on both the entrance and exit sides of the scanner. Fast shuttling at 300in per second is provided, but to avoid rough handling of the tape at the end of the reel it is automatically slowed before the end is reached.

SCANNER

The large angle of wrap round the scanner drum of course calls for particular attention to reduce friction. It comprises an upper part rotating at 50 or 60 revolutions per second carrying the record, replay and erase heads, and a lower fixed part. The rotation of the upper part produces efficient local air lubrication, but special attention has to be given to the surface finish of the lower part to develop an adequate air film at the much lower relative tape speed, especially when in slow motion.

The optimum finish, arrived at after many tests under various environmental conditions, comprises machining the surface in a pattern of fine grooves of a particular form, the surface being finally anodized by a special



(a)

(b) (c)

Figure 5. The substantial construction of the MR1, which has eliminated the problems caused by mechanical weakness of earlier helical recorders, is illustrated by these representative components: (a) the transport base casting; (b) longitudinal head assembly; (c) scanner exit guide

Figure 6. One of the reel drive assemblies, in which the motor drives the reel directly. This also illustrates the unitized type of assembly used throughout the MR1 which facilitates maintenance

process which applies a durable finish whilst not spoiling the groove pattern. A low coefficient of friction is achieved with little variation with temperature and humidity.

Time base correction

The features of the transport design described above provide a greatly improved stability in tape movement, but, as with all other types of recorder, electronic time-base correction must be applied to the output signal in order to satisfy broadcast standards. For the VPR-1 a new wide-range digital time-base corrector, the TBC-1, has been designed. The TBC-1 also compensates for the timing changes that occur in the still-frame or slow-motion modes as a result of the change in tape speed, and thereby brings these modes up to broadcast quality (figure 7).

Automatic scan tracking

The Automatic Scan Tracking system for the VPR-1, AST*, is a major new development in the field of video tape recording which enables the recorder to provide valuable operational facilities not hitherto available. The AST* system comprises an additional head for replay which can move laterally, the head movement being automatically controlled by a closed-loop servo. Tracking errors are detected by continuous measurement of the envelope of the r.f signal from the replay head and a correction signal is developed which is applied to a mechanical transducer, a ceramic piezo-electric element, to which the replay head is attached. The range of movement of the head covers several track widths, and it is therefore able to follow the recorded track in the still-frame or slow-motion modes where the track angle changes. This eliminates the 'noise bar' otherwise visible in the picture which occurs with a normal fixed head when the scan leaves the recorded track (figure 7). While the presence of the noise bar may be tolerable when still-frame or slow-motion are used for basic editing purposes, with AST* fitted and the TBC-1 time-base corrector in use pictures of full broadcast quality are obtained.

EDITING CAPABILITY

The combination of the non-segmented, field-per-scan helical format of the VPR-1 with AST* and time-base correction makes it possible to edit video tape in the same way as film, using the still-frame and slow-motion facilities. Video recordings can be examined frame-by-frame, forward or backward, at any point in a 90-minute programme, as can be done with film on the well-known 'Movieola' editor.

ELIMINATION OF INTERCHANGE TRACKING PROBLEMS

The automatic tracking capability of AST*, coupled with the high inherent tracking accuracy of the new transport, gives the high interchange confidence essential in broadcasting operations. While not necessary to guarantee interchange under normal conditions, the AST* system can eliminate the tracking uncertainties caused by abnormal tape dimensional variations which can sometimes arise through rough handling, temperature and humidity, age or defects in manufacture.

ADVANTAGES OF SEPARATE REPLAY HEAD

A separate replay head as afforded by the AST* system has some very useful practical advantages. First, the head may be used during recording to monitor the

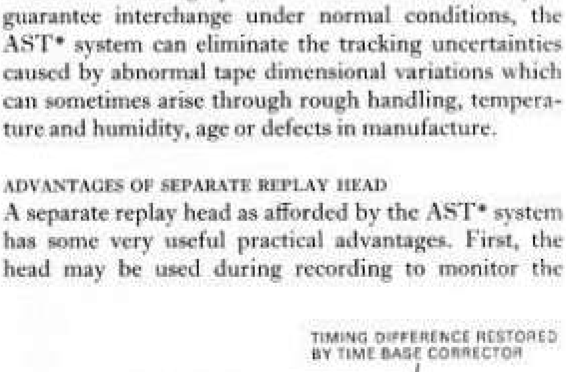


Figure 7. Illustrating the origin of tracking and timing errors in still-frame or slow-motion modes, and their elimination with the aid of AST and time base correction (not to scale)*

recorded track at normal replay quality and so afford video confidence. Second, the replay head provides a most convenient method of record optimization. Third, in design the record and replay heads can be optimized for their specific functions, and thus the compromises involved in the single record/replay head can be avoided.

Relative performance of quadruplex and the VPR-1 video tape recorders

Although the quadruplex v.t.r is capable of an excellent performance, producing first generation recorded pictures often indistinguishable from the original, this demands a considerable setting-up and maintenance effort. In a survey of quadruplex v.t.r usage at a major British independent television company, line-up procedures required nearly a quarter of the scheduled machine time, according to Kelly and Urban.[9] They add that the actual time devoted to alignment was probably nearer 10%, but until a greater certainty of performance is shown, it would not be possible to reduce the scheduled line-up time.

Because the performance obtainable from a video recorder, at least in terms of bandwidth, signal-to-noise ratio and linearity, is obviously some function of the area of tape used per unit time, the low tape consumption of the VPR-1 calls for some comments. It is first of all clear that the original Quad I 15in/sec (38cm/sec) of 2in wide tape is no longer necessary, and in the proposed Quad II standard, the same performance can be obtained at half that speed. While the VPR-1 tape consumption is even less at 9.5in/sec (24cm/sec) of 1-in wide tape, and its writing speed relatively low, the relatively gentle head/tape impact of the helical machine enables ferrite heads to be used, with their better h.f response.

It seems likely that the overall subjective picture quality on the average, especially after a number of generations will not be very different in the two types of v.t.r, bearing in mind the absence of head-banding in the non-segmented helical.

In audio performance the helical recorder has the advantage of the longitudinal orientation of the magnetic particles in the tape, whereas in the quadruplex tape this has to be transverse in the interest of the video tracks.

Format standardization

At the time of writing, working parties of the SMPTE and of the EBU are near to agreement on 1-in non-segmented helical recording standards for 525 and 625 line television systems. Both Marconi and Ampex have plans in hand for the ready accommodation of any changes from the present MR1 and VPR-1 format for users who wish to adopt the new standards. A detailed discussion of the formats will therefore remain for the time being a subject for a further article.

Acknowledgement

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References

[1] L. H. GRIFFITHS: 'Video tape recording – today and tomorrow,' *BKSTS Journal*, December 1976, pp.367–373.

[2] F. DAVIDOFF: 'Digital Video Recording for Television Broadcasting,' *J.SMPTE*, Vol.84, No.7, July 1975, pp.552–555.

[3] EBU Statement concerning helical-scan television tape-machines 625 line/50 field systems, 16th December, 1971.

[4] A. TODOROVIĆ: 'Present Situation of Magnetic Recording,' 10th International Television Symposium, Montreux 1977, *Symposium Record E-1*, pp.1–9.

[5] J. ROIZEN: 'The History of Videotape Recording,' *Journal of the Royal Television Society*, Vol.16, No.1, Jan–Feb, 1976, pp.15–21.

[6] R. S. O'BRIEN AND R. B. MOORE: '101 Years of Television Technology,' *JSMPTE*, Vol.85, No. 7, July 1976, pp.457–480.

[7] C. E. ANDERSON: 'A New One-Inch Helical Machine for Television,' Lecture to FKTG, Freiburg, 7th October, 1976.

[8] R. A. HATHAWAY AND R. RAVIZZA: 'The Design Philosophy of the VPR-1 Helical Scan Machine with Automatic Scan Tracking,' 10th International Television Symposium, Montreux, 1977, *Symposium Record E-6*, pp.1–9.

[9] P. N. KELLY AND C. E. URBAN: 'Video Tape Recording Standards,' International Broadcasting Convention, 1976; *IEE Conference Publication No.145*, pp.31–35.