A Second Generation Type-C One-Inch VTR

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This article deals with the design of a second generation Type-C videotape recorder and the development of a new tape transport and movable tape-guiding system. Topics covered include the use of the NASTRAN structure analysis program to determine deck rigidity, and the development of new video and audio head technology, with a review of the composite single and polycrystal video head and the amorphous metal audio head. Also discussed are improvements in the technology surrounding Dynamic Tracking, and the application of this technology to provide for variable-speed play from three-times forward to one-time reverse; the application of microprocessors to video recording systems; and the specific application of a microprocessor to the servo sub-systems.

The sponsorship of standards by the SMPTE and EBU in 1978 for the Type-C format triggered a remarkable worldwide acceptance by professional television organizations of the 1-in. helical scan VTR. During the very short period of four years, the number of machines produced on the Type-C format is comparable to that of 2-in. quadruplex. Some of the reasons for this rapid growth are:

- Excellent quality, high reliability, and ease of maintenance.
- Easy operation, flexibility in editing applications, and portability.
- Drastic reduction in operating costs and in capital costs.

Over the relatively brief four-year history, a great deal of experience has been gained in manufacturing. This experience, combined with advances in technology, allowed the development of a VTR utilizing new concepts. This paper describes certain aspects of such a VTR, the SONY BVH-2000, which we feel deserves the title of "A Second Generation Videotape Recorder." This recorder makes use of major improvements in the area of:

- New tape transport and movable guide system.
- Improved video and audio performance.
- Improved dynamic tracking performance of slow motion (continuously variable speed from −1 to +3 times normal speed).
- Compact size and low weight with total front access for ease of operation and maintenance.
- Built-in time-base corrector.
- Microcomputer controlled servo system.
- Full scale editing.

Obviously, the length of this paper will not allow for a complete discussion of all of these items in detail; therefore, we will touch briefly on selected areas.

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Tape Transport and Movable Guide System

A characteristic of videotape is the ease with which it can be physically distorted. The design of a tape transport is crucial to the reduction of both static and dynamic loads placed on the tape. Any improvement in tape handling should result in increased tape life and improved interchangeability.

The most significant improvement in tape handling is made by the reduction of friction in the tape path. This can be accomplished by:

- Minimizing the number of fixed guide posts, which in this design has been reduced from 10 to 5.
- Reducing the total wrapping angle around the fixed guide posts from 390° to 260°.
- Using high-accuracy roller guides wherever possible.

Ease of threading and operation is desirable, but has been a problem for the Type-C VTR due to the high angle of wrap around the scanning assembly. The introduction in the BVH-2000 of an automatically operated movable entry and exit guide system (together with the shield cover for the audio and erase heads), provides enough space for easy tape threading. A diagram of

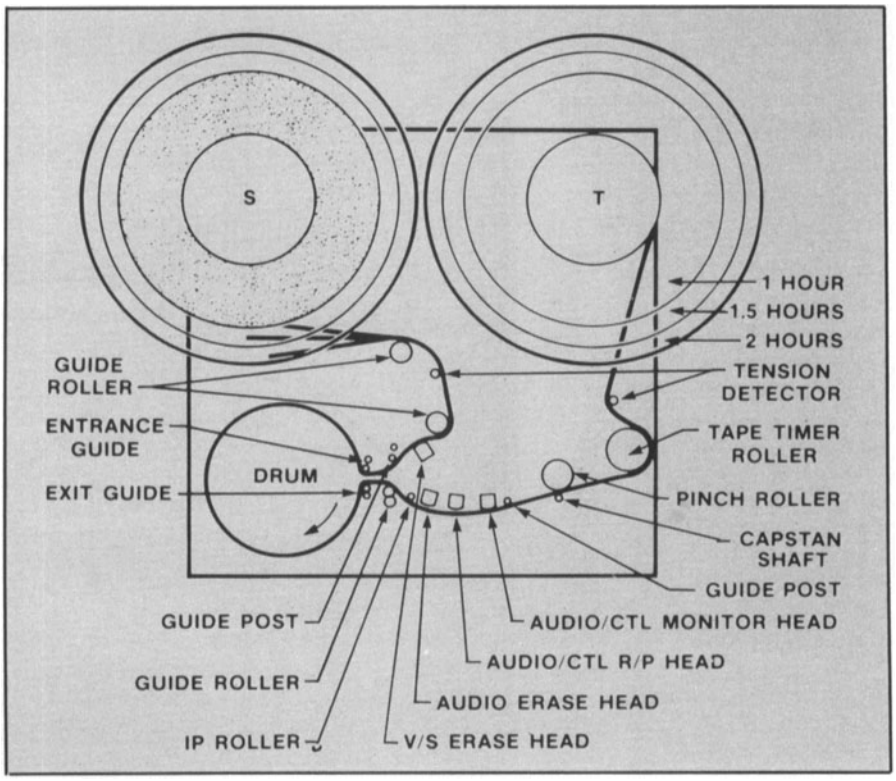

Figure 1. New tape transport system.

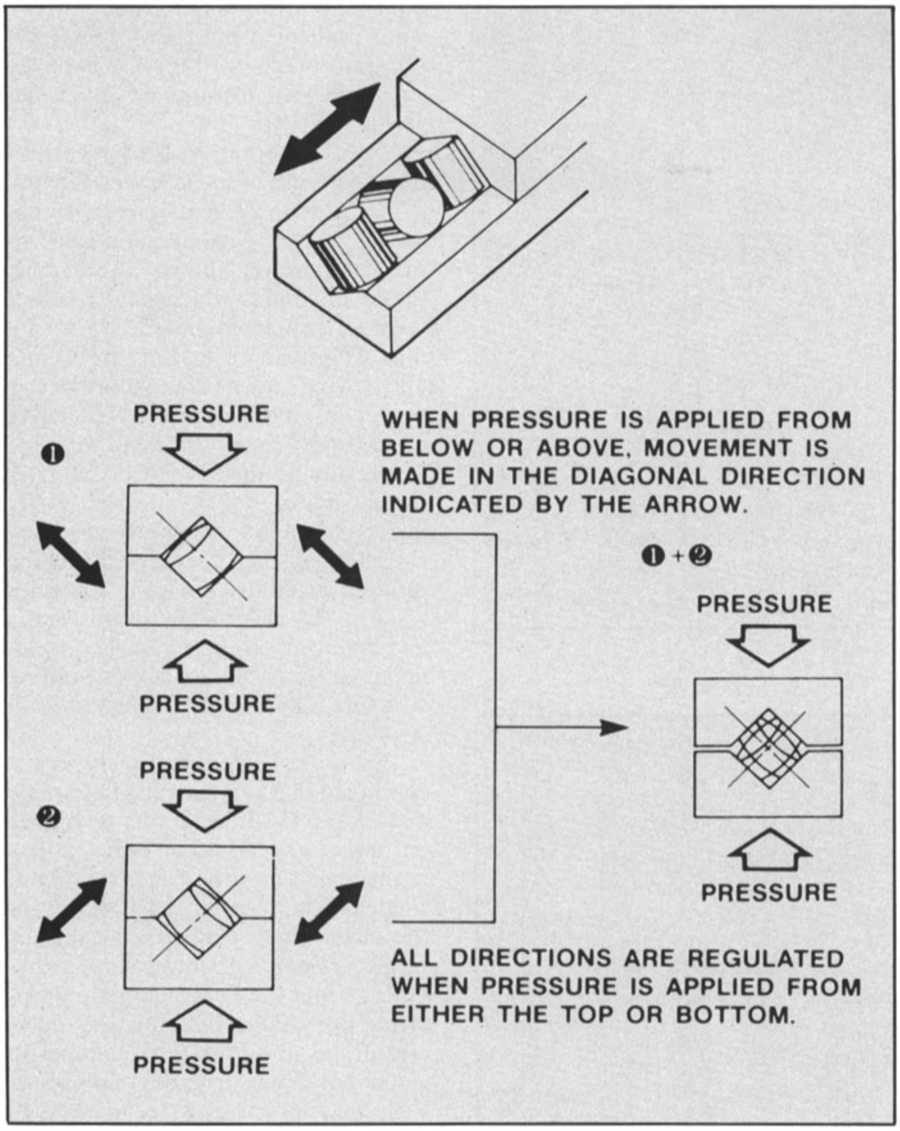

Figure 2. General concept of cross-roller guide system.

the transport illustrating the basic tape path is shown in Fig. 1.

History has shown that the application of a movable guide system must be undertaken with great care, as guide position errors can affect the stability of tape movement and tracking accuracy. This new design employs an extremely accurate cross-roller system which guarantees positioning of the guide to within 1 μ over extended use. Figure 2 illustrates the structure of the cross-roller guide system. The rollers, having freedom of movement in the direction of rotation, are arranged so that their axes are alternately perpendicular. This arrangement results in precise movement of the slant guide carrier with no need for clearance between the rollers and the guide carrier. When the guide carrier end-stop is set, positional accuracy of the guide is guaranteed.

A reduction in size and weight of the transport base plate without a loss of strength and rigidity requires careful structural analysis. During the design of the new transport, the NASTRAN (NASA Structure Analysis) computer program was used. This program computes the stress concentration over a selected grid of elements. Repeated simulation while varying loading, restraint, and degrees of freedom, established an optimum structure based on an aluminum die casting with extensive rib reinforcement. Figure 3 shows the distribution of stress on the initial structure with the area of the capstan motor mounting showing a

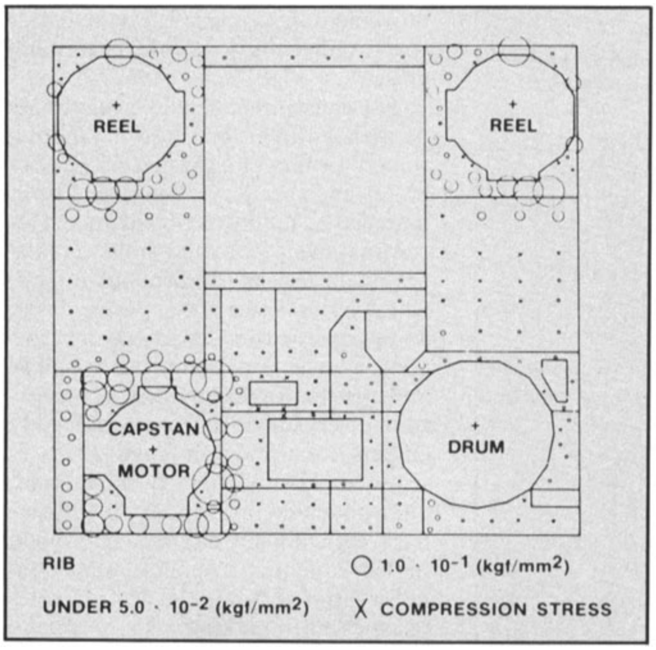

Figure 3. Distribution of maximum main stress (tensional) on the back surface of the base plate (first stage).

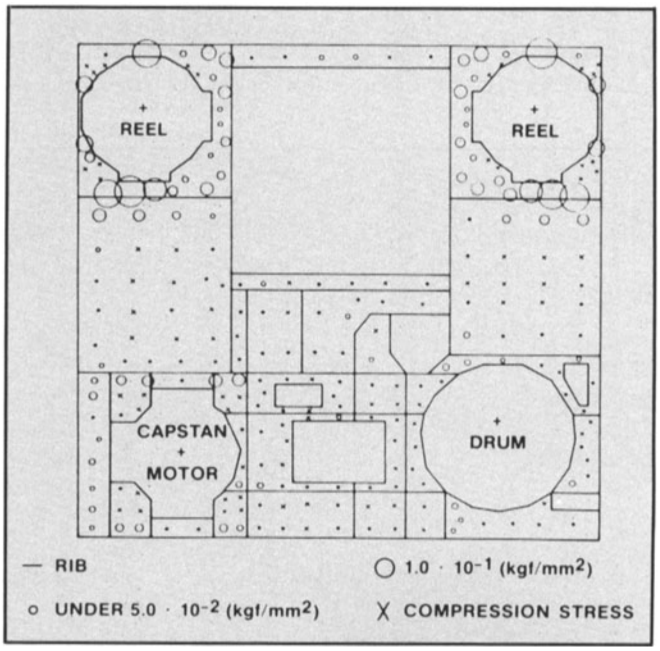

Figure 4. Distribution of maximum main stress (tensional) on the back surface of the base plate (last construction).

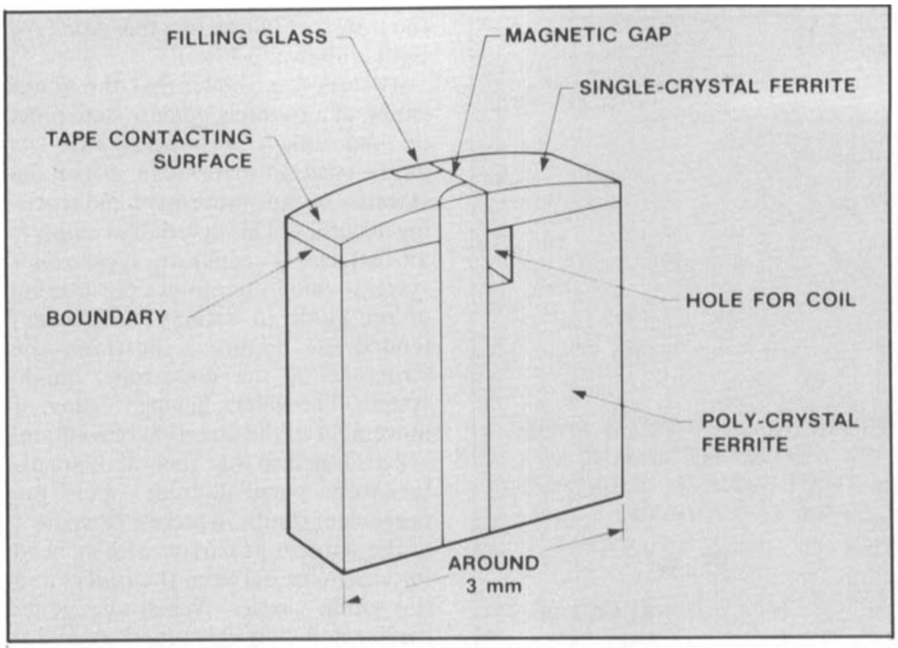

Figure 5. Structure of single and polycrystal ferrite head.

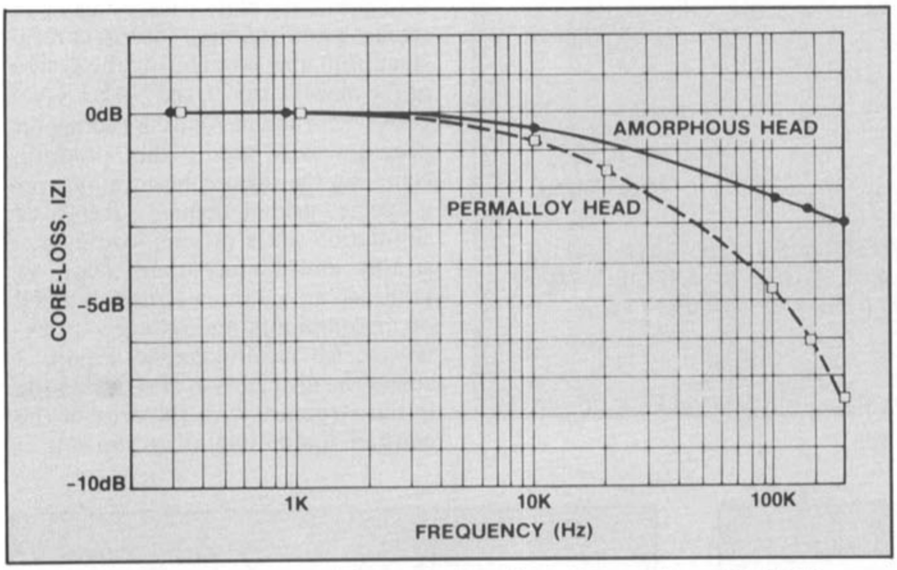

Figure 6. High-frequency characteristics: comparison of amorphous and permalloy head.

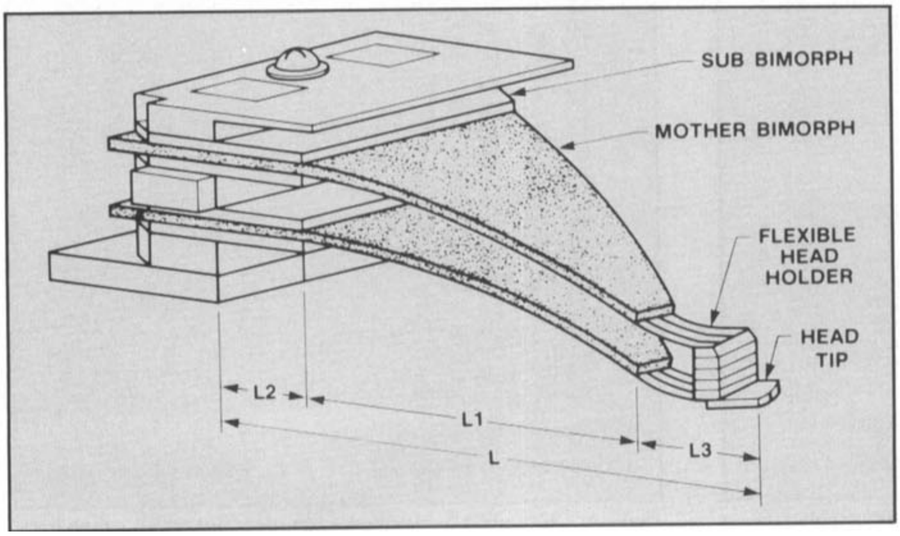

Figure 7. New Dynamic Tracking head.

high concentration of tensional stress. The result of using the NASTRAN program is seen in Fig. 4, where the stress has been distributed over a wider area.

Video recording heads have, until now, made use of single crystal ferrites. These exhibit excellent wear resistance and have quite good magnetic performance; however, being anisotropic, they exhibit noise which is the result of the contact pressure between head and tape. This pressure deforms the crystal, and owing to its magnetostrictive properties, induces an electro-motive force (EMF) across the head winding. The resultant noise is called sliding or scrape noise. Polycrystalline ferrite makes use of a randomly oriented collection of small particles. While the random orientation of the particles results in no bulk magnetic anisotropy and reduced scrape noise, the resistance to wear of the polycrystalline structure is inferior to the single crystal structure.

Figure 5 shows the two materials combined in a single head. The single and polycrystal head has a higher output, a lower scrape noise, and a higher reliability than the traditional single crystal ferrite head. The part of the head which contacts the tape is single crystal with high wear resistance, while the bulk magnetic properties are determined by the polycrystalline material. This composite video head construction, combined with new processing techniques to control deterioration of magnetic characteristics due to gaps at the boundary, results in a 1–1.2 dB improvement in scrape noise and a better spectral distribution of the remaining noise.

The conventional audio head utilizes permalloy rather than ferrite material, since the magnetic characteristics are better and there is a lesser need for a material of high wear-resistance. Recently it has become possible to make practical use of amorphous metal, which has a better initial permeability and magnetic flux density than permalloy; a lower variation in permeability and magnetostriction with temperature; no crystal anisotropy; small eddy current loss; and improved wear-resistance. Considering these factors, amorphous metal is an excellent material for audio heads which have good high-frequency response, signal-to-noise ratios (SNR), and wear characteristics. By making use of ferrite masking over the area not occupied by the heads, resistance to wear is further enhanced, and a reduction in tape adhesion is realized. In Fig. 6, we see the relative high-frequency characteristics of permalloy and amorphous metal heads.

Dynamic Tracking System

The ability to obtain broadcast-quality playback at other than normal play speeds is being used in increasingly more sophisticated ways. This has encouraged designers to improve such systems in both quality and range. The recorder described here makes use of several major advances that have been made:

- A new form of construction is employed for the Dynamic Tracking (DT) head allowing a peak-to-peak deviation of 750 μ to be achieved and a self-resonance frequency of about 1250 Hz.
- A correlation search type of DT following circuit has been developed guaranteeing perfect tracking even at

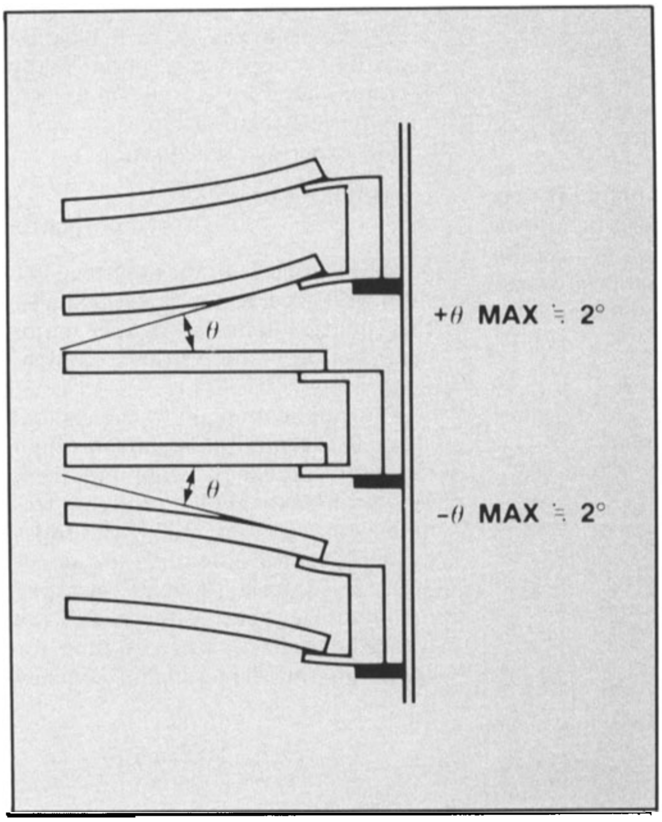

Figure 8. DT head motion-tape contact.

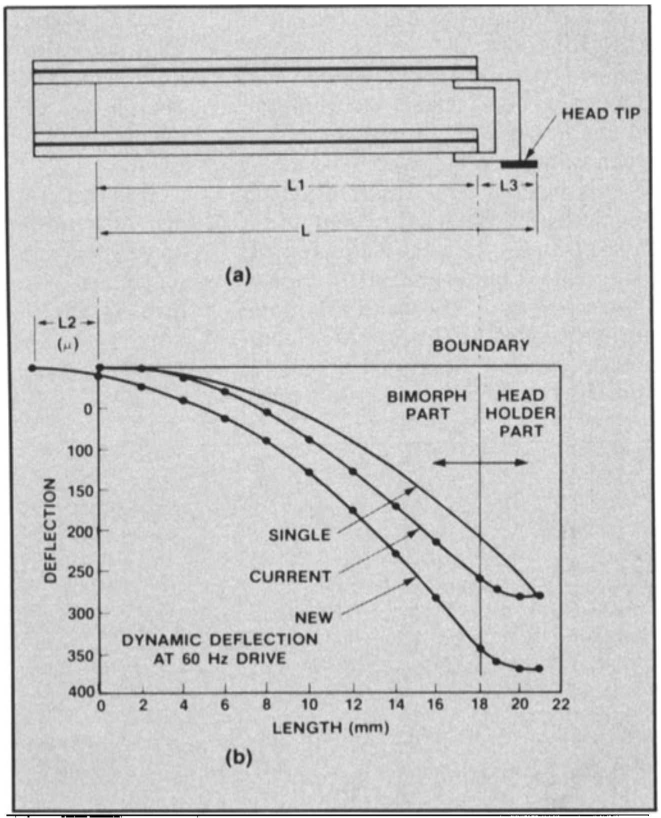

Figure 9. (a) Current twin DT head; (b) bimorph deflection curve.

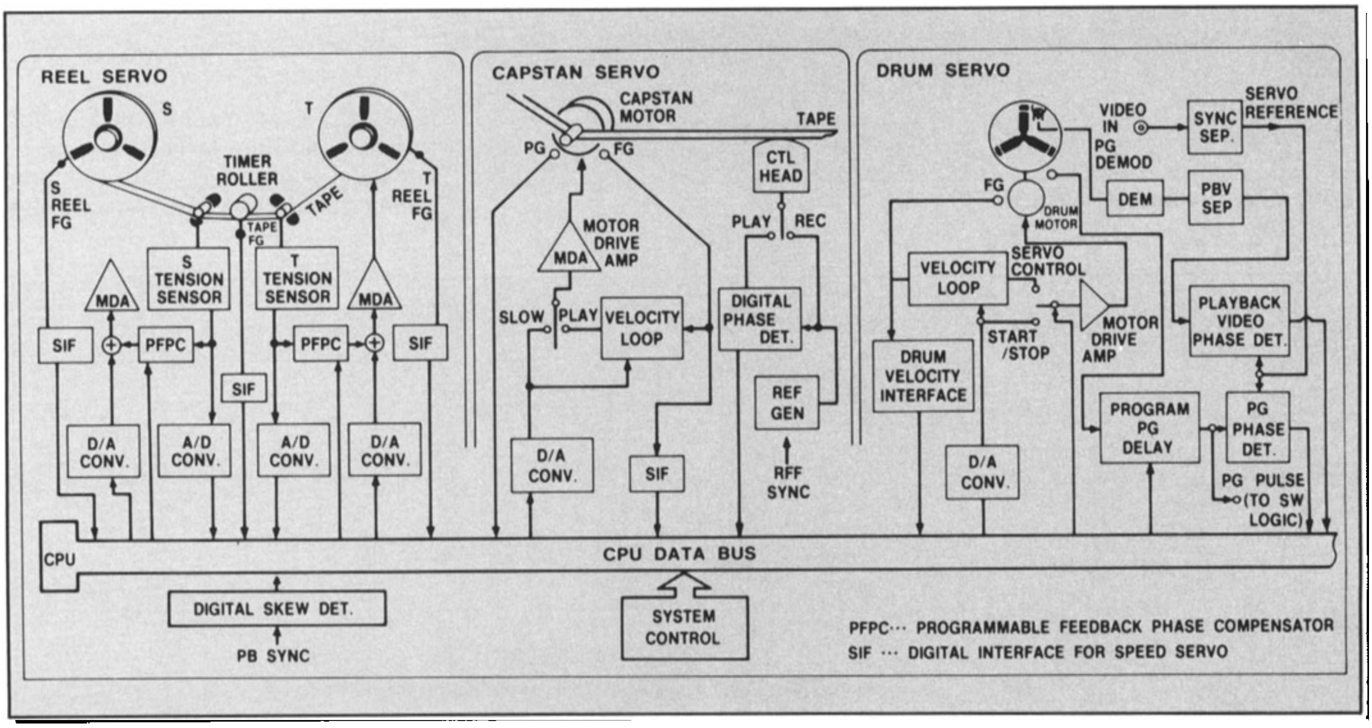

Figure 10. Computer servo system.

normal speed in reverse, where the required deviation performance is a serious problem.

- A digital trace control circuit has been implemented giving stable high-speed responses to track jumping and tracing.

As a result, a speed range of −1 to +3 times normal speed is now possible. Newly added features are programmed play and a variable-speed learn function.

The Dynamic Tracking video head is mounted on a piezo-electric bimorph which moves the head transversely when voltage is applied. Early versions of this head used a single bimorph, which caused the head to contact the tape at an angle when deflected. By using a dual bimorph construction as shown in Fig. 7, the head maintains normal contact to the tape. The characteristics are determined by L_1, L_2, and L_3. The deviation is proportional to the square of L_1, but with a disadvantageous reduction in resonant frequency. L_2 increases the effective bending length and deviation but the rigidity of the joint maintains the resonant frequency. The length of the flexible head holder (L_3) is about 4 mm, and does not significantly reduce the bending action while being able to perform the function of compensating the head contact angle. A careful analysis of the material, its dimensions and form, is necessary for the flexible head holder to keep its stress below an acceptable value. Figure 8 shows the result.

It is rather difficult to find the precise relationship between the applied drive voltage and resultant head displacement in such a composite structure. In the initial design the equation:

$$\delta = \frac{d_{31}V}{h_1 + 2h_2} l^2$$

where:

δ	=	End point displacement
d_{31}	=	Piezo-electric constant
V	=	Field intensity in the bimorph
$h_1 + 2h_2$	=	Thickness of ceramic and shim
l	=	Effective bimorph length

shows that the bending is proportional to the square of the effective length. Each bimorph has its own bending sensitivity, dependent upon many factors. Therefore, it is useful to have an empirical relationship.

The experimental equation:

$$\delta = 0.01482 + 0.01426l + 0.7253l^2 - 0.0007l^3$$

has been found to fit the described DT head with good accuracy. Incidentally, this equation demonstrates the major contribution made by the l^2 component.

The application of a trapezoidal shape to the bimorph results in a high resonant frequency being obtained. While an even higher resonant frequency may be obtained if the edges contained a quadratic curvature, about 30 Hz in 1250 Hz, the relative ease of manufacture dictated the use of the trapezoidal shape. The equation for approximating the resonant frequency is:

$$F_c = \frac{1}{2\pi l^2}\sqrt{\frac{EI}{m}f(K)}$$

where:

$$EI = \frac{2}{3}\left[E_1\{(h_1 + h_2)^3 - h_2^3\} + E_2 h_2^3\right]$$
$$m = 2(s_1 h_1 + s_2 h_2)$$

where E_1, E_2 are Young's modulus for ceramic and shim respectively; s_1, s_2 are the specific gravity of ceramic and shim respectively; $\sqrt{f(K)}$ is a constant

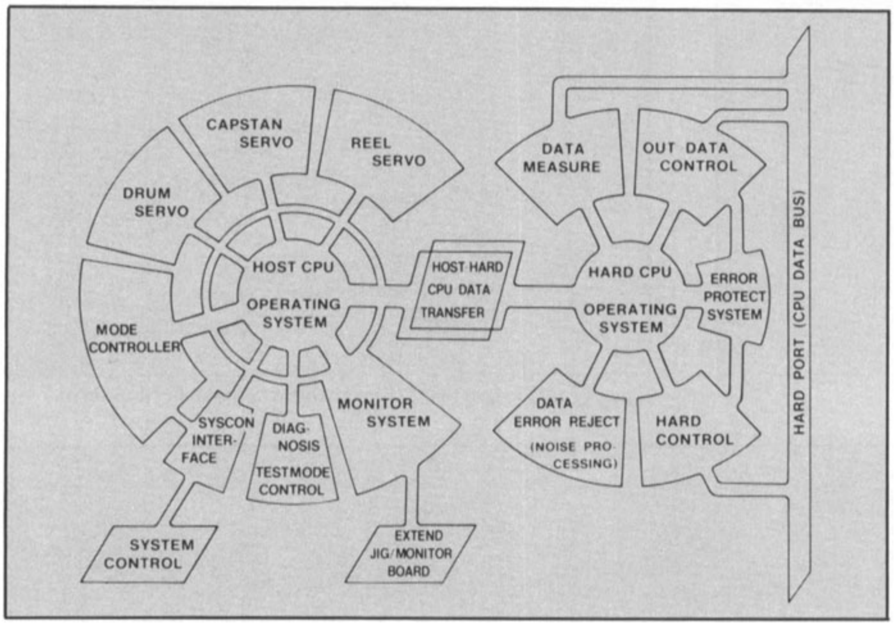

Figure 11. Servo software block diagram.

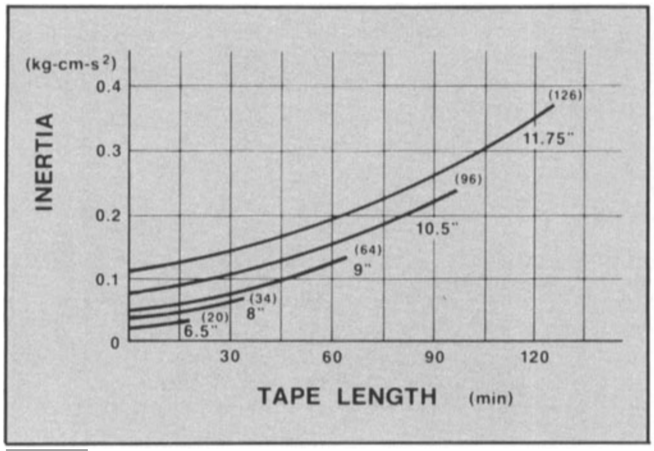

Figure 12. Inertia (tape + reel + reel table).

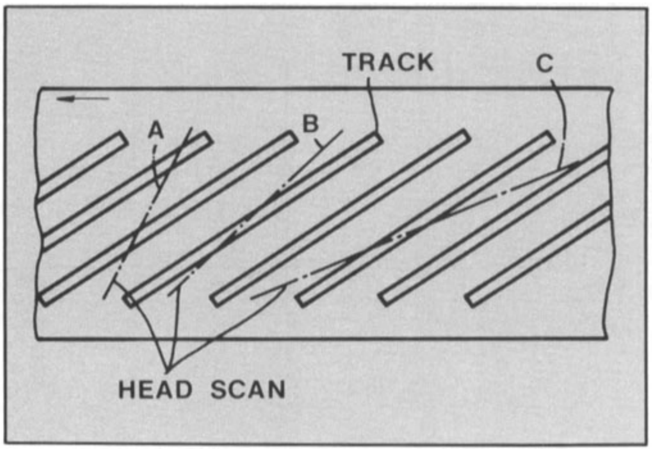

Figure 13. Operation of DT servo system.

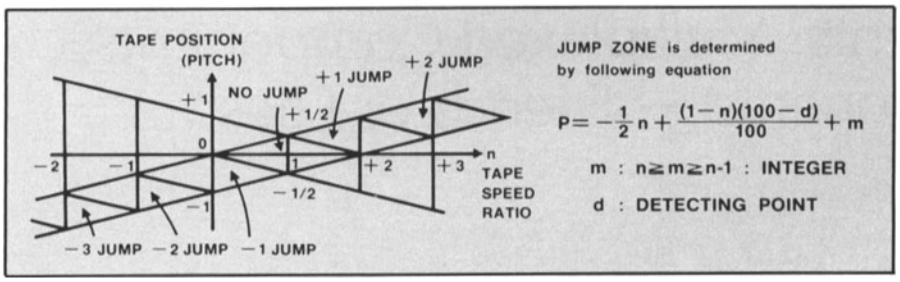

Figure 14. The digital trace control circuit calculates the jump to another video track.

dependent on the trapezoid shaping being between about 3.5 for a rectangular shape and 7.5 for a triangular shape. It can be seen from this equation that nearly a 2:1 increase in resonant frequency can be obtained by adopting a trapezoidal shape. Also, an increase in t reduces the resonant frequency in the same ratio as deviation is increased.

Figure 9 shows a comparison of deflection characteristics for the new DT head employed in the BVH-2000, the DT head used in the BVH-1100A, and the older single bimorph DT head. The compensating effect of the flexible head holder in the double bimorph is clearly seen in the increased deflection of the latest version.

Microcomputer Controlled Servo System

The servo system in a videotape recorder has traditionally been realized through the use of a direct application of analog and digital circuitry. The BVH-2000 uses a combination of analog, digital, and micro-processor techniques to provide both high speed and dynamically changing response based on varying conditions. Figure 10 shows the block diagram of the overall machine servo system.

The system sends through the central processing unit (CPU) all input data related to speed, phase, and tension; control of servo motors; and output data to the system control. The basic servo operation makes use of analog hardware where high-speed response (frequency response) is required. This can be seen in the drum and capstan servo velocity loops. Where relatively static values are required, stable performance is assured by means of digital processing techniques through the CPU. The most significant feature of this CPU-based servo system is its ability to respond to varying conditions. These transients are controlled based on the system programming being optimized for the most desirable tape speed and tension relationship.

System diagnostics and self checks are performed in both software and in hardware during operation to provide a fail-safe condition in the case of any misoperation or hardware failure.

The CPU system consists of two Z-80 microprocessors. Servo operation is divided between the CPUs, with one handling hardware I/O control (the hard CPU), while the other (the host CPU) provides servo system control, processes servo data, and provides for external monitoring of the system. Figure 11 shows the relationship of the processors. The two processors operate independently of each other and perform their respective functions simultaneously. As a result of the constantly changing conditions in the system, large quantities of data must be transferred between the CPUs at a high speed. This transfer is through a common RAM area and is at a rate of 4 times in each field. The maximum sampling rate for the hard CPU is 480 Hz, while the rate for the host CPU is 120 Hz. The operating system is contained in E-PROM, with the program occupying less than 14.5K bytes for the host CPU and 6K bytes for the hard CPU.

An example of the system's ability to respond to varying conditions can be seen in the operation of the reel servo. Figure 12 illustrates the relationship between inertia and tape length; however, under some conditions the variation of total inertia can be 10 to 15 times that shown. The best tape control can be obtained by calculating the access torque control:

$$ATC = (J_t + J_r + J_{rm})\left(\alpha_c + \frac{\alpha_s - \alpha_c}{K}\right)$$

where:

J_t = Tape inertia (calculated diameter)
J_r = Reel inertia (measured and calculated)
J_{rm} = Reel table and motor inertia
α_c = Access command (from power control)
α_s = Access sense (measured by reel FG)

During the design stage of the BVH-2000, a high-performance diagnostic and monitor system was developed, based on the requirements surrounding program development and debugging. The development of this system continues based on the analysis of discussions regarding requirements of the production line, field service, and customers. Many of the diagnostic functions are presently resident in the system and are easily accessed for normal maintenance, while other specialized test and diagnostic routines continue to be developed.

Dynamic Tracking Servo

The DT servo system is realized in a digital trace control and in a correlation search follower circuit. While a description in detail would be too lengthy for this paper, the theory of operation can be seen by referring to Fig. 13. The DT servo controls the head scan in a manner similar to *A* or *B* or *C* when tape speed is other than normal, or if the recorded track varies. The circuitry required to perform this may be considered as three separate items: Ramp compensation, Position shift, and Jump control. The follower circuitry is used to compensate for position shift, and since this has been described in detail in other papers, it will not be discussed. The other two items are controlled by the digital trace control. Referring to Fig. 14, the digital trace control circuit calculates the moment, the direction, and the distance of the jump to another video track. This decision can be seen in the chart, where playback vertical phase is represented in the vertical axis as Tape Position, and the playback sync frequency represents Tape Speed in the horizontal axis. The equation shown is used to determine the jump area. Based on this, a speed range of −1 to +3 times, play can be assured.

Conclusion

Many new and exciting developments have occurred since the standardization of the Type-C 1-in. VTR. Some have been progressively introduced, but many have had to await the introduction of a new model due to the need for compatibility between subsystems. Encouraged by the rapid acceptance of the Type-C recorder, an extensive amount of time was invested to realize the numerous improvements in performance achieved in the BVH-2000. The realization of these advances justify, it is felt, the title of "A Second Generation Type-C One-Inch VTR."