The Honeywell-96 instrumentation recorder: What was magnetic tape recording again?

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Introduction

Taking measurements without recording the results is rather pointless. Therefore, scientists and/or engineers have always tried to find new and suitable ways of recording their results. The methods used range from simply taking notes with pencil and paper to applying highly sophisticated data-acquisition systems. When it comes down to rapidly varying quantities, we need instruments for their registration. Before digital techniques took off, analogue registration was quite common, using magnetic tape recorders. The best-known applications are in sound recording with reel-to-reel and compact cassette recorders, and in video-recording using systems such as VHS and VCR. However, in many other fields there is the need for recording sensitive measurement data, such as in biomedicine using the well-known ECG (electrocardiogram) or the EEG (electroencephalograms). Other fields with a similar need are geophysics (seismography), aerospace (flight recorders, wind tunnel experiments) and hydrology (model studies).

For all these purposes, a special class of magnetic tape recorders has been developed usually, referred to as instrumentation recorders. In this contribution some technical aspects of instrumentation recorders will be explained, with special emphasis on the Honeywell-96: an interesting example present in the historic collection of our Electrical Engineering department.

The basics of magnetic recording

Though a thorough discussion of magnetic recording is beyond the scope of this article, the main aspects are illustrated in figure 1.

The magnetic tape consists of a plastic base (usually acetate or mylar) and a coating of ferrous oxide particles. Commonly employed thicknesses are 0.5 mil, 1.0 mil and 1.5 mil (approximately 13 µm, 25 µm and 38 µm). The tape is transported from reel 1 to reel 2. The tape passes over a small idler before passing over the recording and the reproducing heads (write and read head). The tape then passes in be-

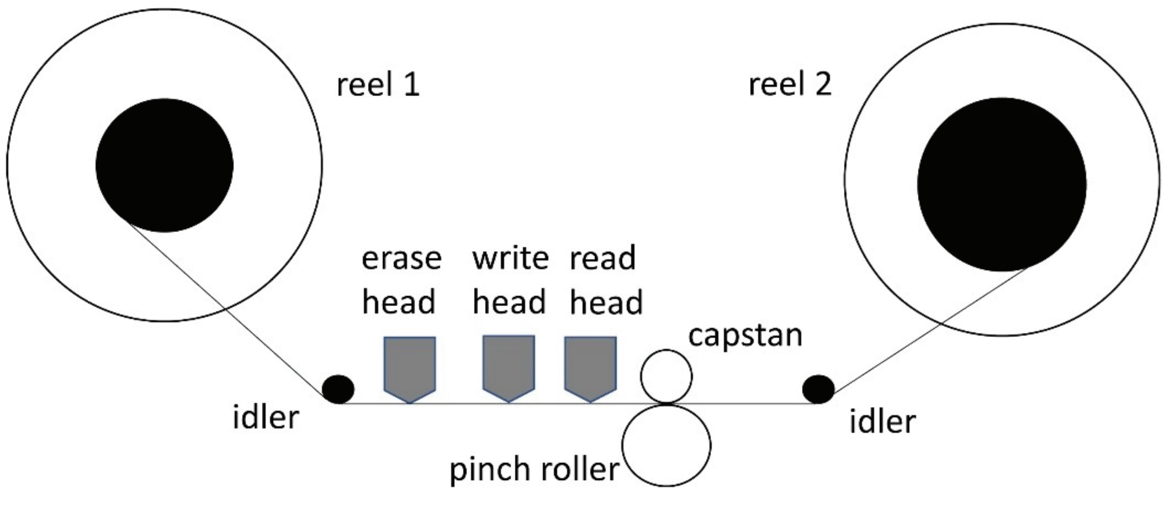

Fig 1: The basic tape recorder

tween a motor driven capstan and a rubber pinch roller, hence being transported at a constant speed. After leaving the drive mechanism the tape passes another idler and is then fed to the second reel. Both reels are powered by separate motors. As will be discussed later in more detail, it is crucial to keep both the tape speed and the tape tension constant.

Magnetic registration

The tape is coated with an acicular (needle shaped) form of ferric oxide (Fe2O3) The particles are about 0.2 to 0.8 µm long with a diameter of about 1/2 to 1/6 of its length (For audio purposes, chromium dioxide (CrO2) was also used.) First the tape is demagnetised by an erasure head to prevent residual signal magnetisation. Magnetisation of the particles occurs when the tape passes a recording head basically being a ring-shaped ferroxcube or mu-metal core and a narrow gap that is a few µm wide (figure 2).

The signal to be recorded is fed to a coil, hence creating a fluctuating magnetic field. Thanks to the narrow air gap, this field penetrates the tape, thus magnetising the particles on the tape. The net result is a remaining magnetisation which is dependant on the originally applied field strength.

Unfortunately, this relation is highly non-linear. It can be proven, however, that, if a high frequency bias current is superimposed on the signal current to be recorded, the net result is a linear relation between the signal current and the remaining magnetisation of the magnetic particles on the tape.

Recovering the signal is accomplished by a replay head similar to the recording head. The variations in magnetisation of the tape passing the gap in the read head give raise to fluctuations of the flux Φ induced in the head. Consequently, a voltage $u = d\Phi/dt$ is induced in the coil of the head. It follows, that the regained signal is the derivative of the recorded signal. Obviously, this can be corrected with an integrating circuit. However, it becomes immediately clear, that the recording of DC or very slowly fluctuating signals is impossible. At the other side of the spectrum, we find that the maximum possible frequency to be recorded is dependant on both the tape speed and the gap width such that: $f_{max} = v/d$ with v being the speed of the tape passing the head and d the gap width. In practice the value of f_{-3dB} is much lower than f_{max}.

Deviations from perfection

Ideally, the tape passes the head without any mechanical distortion and at a constant speed and with perfect mechanical contact between tape and head. However, the tape drive system (capstan and pinch roller) and the reel motors exert a longitudinal force on the tape causing mechanical tension. Fluctuations in the tension cause length variations and hence frequency fluctuations. In audio applications, the audible effect is usually referred to as 'wow' (low frequency fluctuations of less than about 4 --10 Hz, usually due to imperfections in the tape drive system) or 'flutter' (higher frequency fluctuations usually due to the combined longitudinal force on the tape and the stiction at the head. The tape may even vibrate, as if it were a bowed string of a violin!

All these effects can be minimized by stabilizing the tape tension.

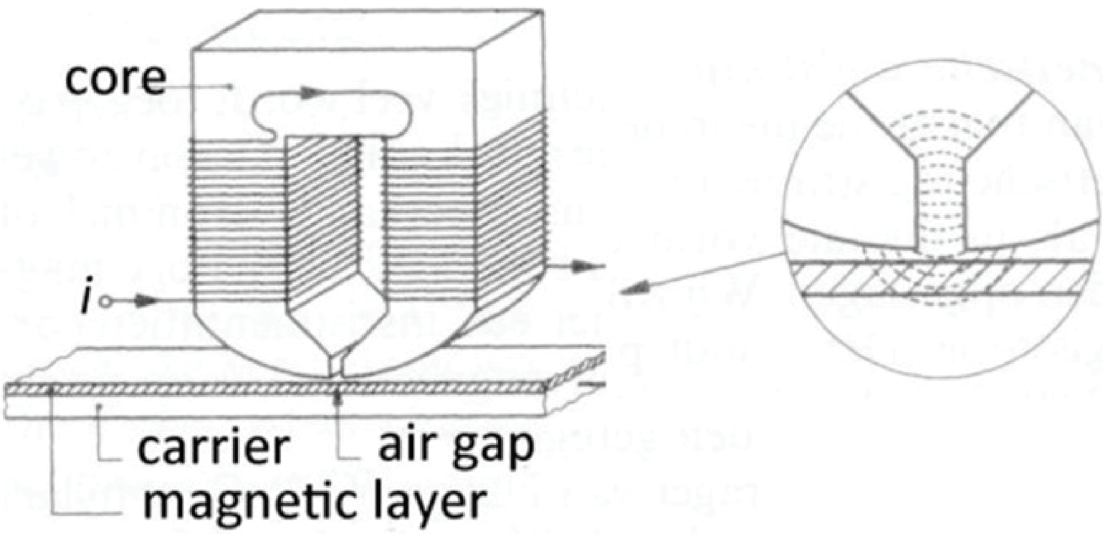

Fig 2: The recording head; detail: magnetic field penetrating the magnetic layer of the tape [1].

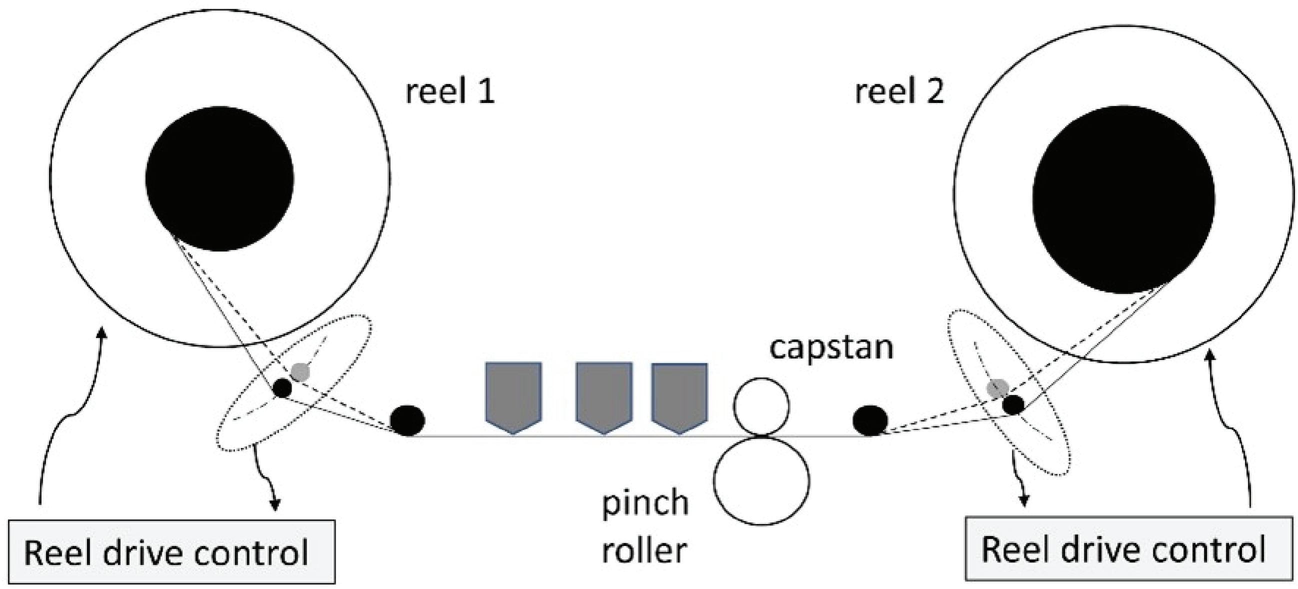

Figure 3: Tape tension control

Therefore, it is of utmost importance to keep the tape tension constant. Two strategies are applied to overcome these problems: The first one is obvious: try to prevent the problems from occurring. If this is not fully achieved, the next strategy is to reduce the effects by some way of feed-back control. The first approach leads tot minimizing the distance between the drive mechanism and the heads. The second strategy consist of controlling the tape tension. Taking into account that rapid fluctuations have to be reduced, we need a fast-responding control system, which imposes special requirements on both the sensor and the actuator.
Traditionally, the tension sensor consists of an idler mounted on a movable arm connected to a potentiometer (sensor). This is called the open loop drive system. The output of the potentiometer is used to adjust the power of the reel motor (actuator). Since the sensor is a mechanic system the response speed is rather limited. Figure 3 shows the traditional system for tension control is shown.

A rather different tape transport and tension control system will be described later when discussing the Honeywell-96 machine.

FM-recording

As mentioned previously, it is not possible to record D.C. or very low frequencies. However, in many applications we want to record signals with frequencies ranging down to 0 Hz. Think of an Electrocardiogram, which is zero valued, apart from periodical electrical heart activity. The solution is to apply frequency-modulation (FM). A carrier (sinusoidal waveform) of e.g., 10.000 Hz is frequency modulated with the actual signal to be recorded. When replaying the tape, the output signal is fed into an FM-demodulator such as a Phase Locked Loop.
We should keep in mind, however, that the bandwidth of an FM channel is much wider than the bandwidth of the modulating signal, which hence limits the allowable bandwidth of the signal to be recorded. Another interesting point is the effect of imperfections in the tape transport system that give raise to frequency fluctuations ('wow' and 'flutter'). In FM recordings, the fluctuations manifest themselves as fluctuations in amplitude, hence: noise or, in the case of periodical fluctuations: undesired tones! Again, this imposes high requirements on the entire tape drive system as well as the tension control. In general: FM recording is less sensitive to amplitude fluctuations (irregular tape-head contact) and non-linearities, but the achievable band width is much less (by a factor of about 0.1).

Some aspects of instrumentation recorders.

In practice, the tape has a number of parallel tracks so that we can record more than one signal simultaneously; and the wider the tape, the higher the number of parallel tracks that can be recorded Commonly used systems employ ¼ inch tapes for 4 channels (e.g. RACAL Store 4), ½ inch tapes for 7 channels (e.g. RACAL Store 7, Philips Ana-log 7) and 1 inch tapes for 14 or more channels (e.g., AMPEX PR2200, Honeywell-96). For FM recordings the Inter-Range Instrumentation Group (I.R.I.G.) has defined a number of standards concerning FM-recording: a common standard is shown in Figure4.

The Honeywell 96

In the mid-seventies of the last century, at that time working at the Bio-medical Engineering Lab of the Department of Electrical Engineering at the TU Delft, I was able to purchase a refurbished Honeywell-96 analogue instrumentation tape recorder. This purchase allowed us to replay, analyse and process ECG's as recorded in academic hospitals. When I joined the 'Studieverzameling' a few years ago, to my surprise, I found this huge instrument there (Figure 5). Its dimensions are 55 cm wide, 73 cm deep and 185 cm high.

The apparatus is a 1 inch tape machine with 14-channels suited for either direct or FM recording. It can run at 9 different tape speeds ranging from 15/16 inch/sec to an amazing speed of 240 inch/sec (6 m/sec!). This latter figure means an amazing speed of 5 m/sec! It may be clear that the design of a tape tension control system for such a device must have been a real challenge.

Firstly, the tape-drive system is constructed such that a smooth transport of the tape is guaranteed for both forward and backward playing. Secondly, the head contact and tape drive have to be placed close together in order to avoid any fluctuations in tape-head contact. This leads to the so called closed-loop tape drive system. Thirdly, such high tape speeds require a fast-responding control system which means that the sensors (plural, since the tape has to run both forward and

Tape Speed Inch/sec	Carrier frequency f_0 kHz	Modulation frequency f_m kHz
1 $^7/_8$	6.750	dc – 1.250
3 ¾	13.500	dc – 2.500
7 ½	27.000	dc – 5.000
15	54.000	dc – 10.000
30	108.000	dc – 20.000
60	216.000	dc – 40.000
120	432.000	dc - 80.000

Fig 4: The I.R.I.G. standards for Wide Band Group I FM recording; Modulation index Δf/ f0 = 0.8 [4]

Fig 5: The Honeywell-96 Instrumentation tape recorder (front door opened, circuit compartment not shown)

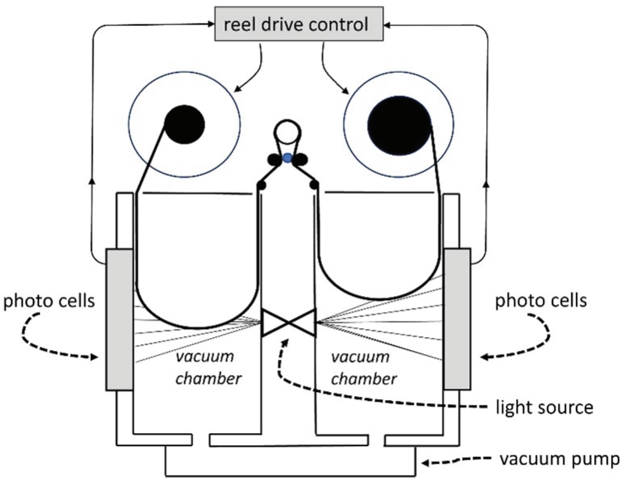

Fig 6: The 'vacuum' tape tension control system (viz. [2])

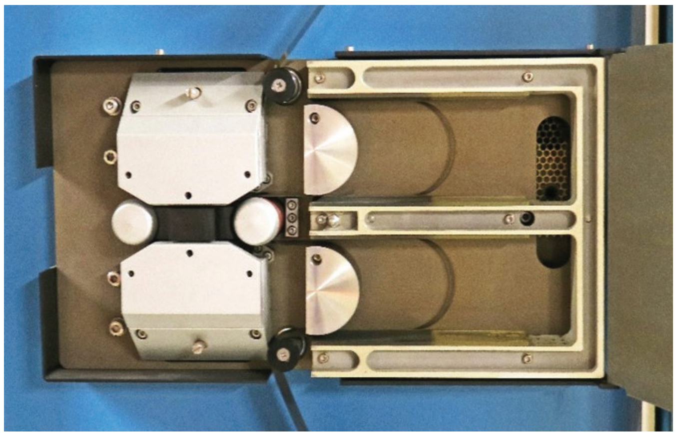

Fig 7: The tape drive, head stack and vacuum tape tension control unit

backward) should ideally contain no mechanical parts. The actuators (i.e. the reel motors) should allow for extremely fast responses, or in other words: extremely high angular acceleration. This can only be accomplished by very powerful reel motors. The solution to the sensor problem is a 'vacuum' tape-tension control system, as depicted in figure 6.

The tape, before and after having passed the transport system, is 'sucked' into low pressure chambers. The low pressure is created by an air pump. Two light sources and two arrays of photo-voltaic elements determine the positions of the tape loops in the low-pressure chambers. The output of the photocells is fed into the motor control systems such, that an equilibrium position of the tape is achieved. In this way the inertia of the measuring system is determined by a small and hence noticeably light segment of tape, which leads to a very fast response time.

The Honeywell-96 tape transport unit is shown in Figure 7, along with the sensor part of the tension control in opened position. The tape is at the reference position. During operation, this section is firmly closed as to allow for the vacuum-system to operate properly. The need for fast responsiveness of the reel drives has led to the use of heavy motors, which can be observed in the photograph of the machine's interior (Figure 8). Part of the vacuum system is also shown (the yellow hose).

Finally, Figure 9 shows the plug-in rack containing the recording and replay modules for the individual channels. As can be observed, many of them have been disappeared over the years....

Final remark

After the introduction of digital techniques, analogue recorders were still used together with pulse-width or pulse code modulation. However, the development of fast digital disk systems and solid-state systems finally made tape recorders obsolete.

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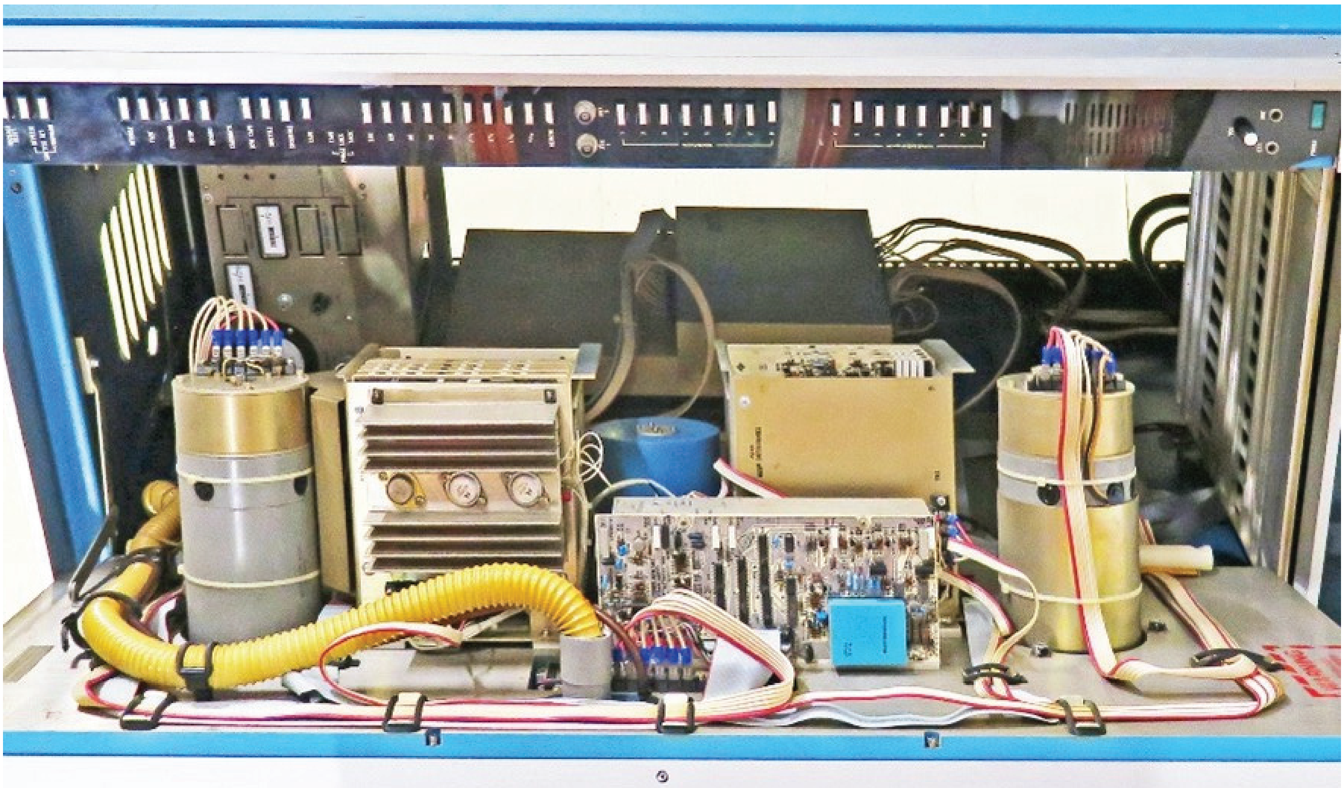

Figure 8: Inside of the machine: note the large reel motors and the yellow hose of the vacuum system

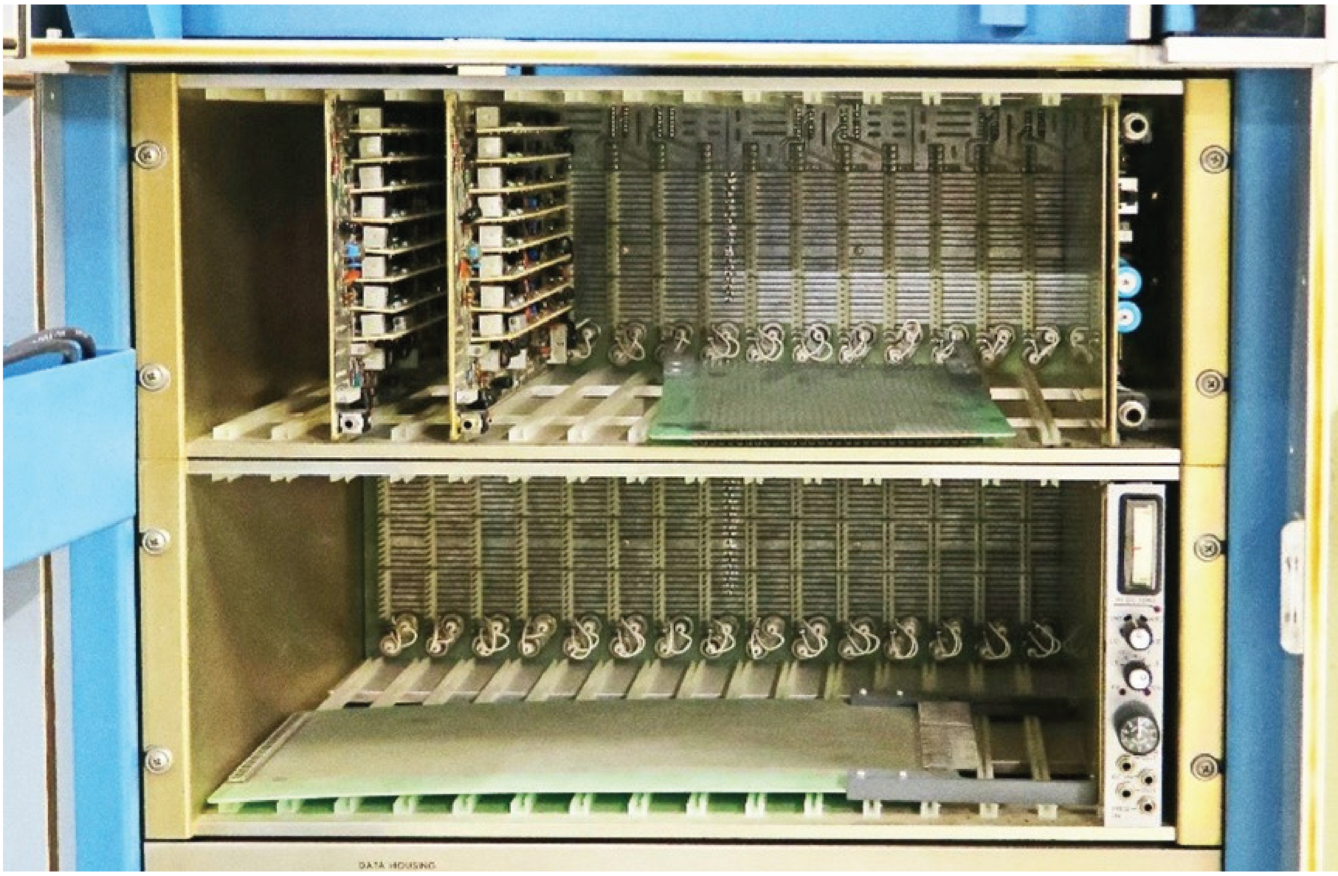

Figure 9: The record and replay units rack.

References

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All photographs and figures, except Figure 2, are produced by the author.

Want to see one of the few operational Honeywell-96 machines in some serious action? Scan the QR code!

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