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# HEAD POSITIONING SYSTEM FOR HIGH DENSITY DISK FILE

R. K. Oswald
F52/013, x3357
SDD San Jose

# Head Positioning System for High Density Disk File

By R. K. Oswald

Increasing areal data density in disk files requires increased track density as well as increased longitudinal bit density if a competitive "cost-capacity" figure of merit is to be achieved. Obtaining an acceptable reliability and error rate in a product environment has required that the maximum static and dynamic radial positioning errors not exceed 20% to 25% of the track width. Introduction of a track following servo in the 3330 file has permitted a nominal 200 tracks per inch radial density while maintaining about the same percentage position error achieved by the mechanically detented 2314 at 100 tracks per inch. Although it is the first application of a track following servo to an IBM disk file product, the track positioning method used in the 3330 cannot provide the positioning tolerance required for extension to significantly higher track densities.

As shown in Fig. 1, one of the 20 disk surfaces in the 3330 contains only position information for the servo, and positioning the servo head on this surface aligns the other 19 data heads of the cylinder. The static and dynamic position tolerances between the data heads of a cylinder and their corresponding data tracks on the disks are the factor in this system which limits its extension to higher track densities. The major sources of mispositioning tolerances are listed in Table 1. These cumulative tolerances can be overcome by including the servo position information directly on each data surface and reading it with the same head element used to read the data. Separation of servo position information and data is then accomplished by time division multiplexing, i.e., placing the position information in small sectors equally spaced around the data tracks. This positioning method has come to be known as a "sectorized track following servo". Some of the design considerations in its implementation will be explored in detail.

A basic question concerning a sectorized head positioning servo is how many sectors are required to obtain satisfactory performance. Since an electromagnetic actuator is inherently a type 2 positioning system, static accuracy is not a representative performance criterion. The dynamic position error sources are basically periodic at the rotational repetition rate of the spindle, and fast accessing requires good step response. Therefore, a good servo performance criterion is the magnitude of the position servo loop gain at the disk runout frequency when the compensation is chosen for good damping. For an example, a typical open loop transfer function for the position servo if sampling (sectors) are not used is

$$G = \frac{\frac{\omega_c^2}{\sqrt{10}}\left(S\frac{\sqrt{10}}{\omega_c}+1\right)}{S^2\left(S\frac{1}{\sqrt{10}\,\omega_c}+1\right)} \qquad (1)$$

where $w_c$ is the unity loop gain radian frequency. If $w_r$ = disk rotational velocity = $(w_c/5.5)$, then $|1 + G(s = jw_r)| = 10.1$, which implies that the position error due to runout will be reduced by about a factor of 10 by closed loop operation of the servo. If, however, the position information is located only in N equally spaced sectors occupying a total of 5% or less of the disk surface, then the open loop transfer function becomes

$$G' = \frac{\frac{\omega_c^2}{\sqrt{10}}\left(s\frac{\sqrt{10}}{\omega_c}+1\right)}{s^2\left(s\frac{1}{\sqrt{10}\,\omega_c}+1\right)} \; \frac{\left(1-e^{-\frac{2\pi}{N\omega_r}s}\right)}{\left(\frac{2\pi}{N\omega_r}s\right)} = G\,T_s \qquad (2)$$

where Ts is the transfer function for a zero order sample and hold. If $w_r = (w_c/5.5)$, the phase margin of G' is about $(5.5/N) * 180°$ less than the phase margin of G. Since G has a phase margin of 55° and about 45° is a minimum for desirable transient response, if $(5.5/N) * 180 = 10$, $N = 99$.

For a longitudinal recording density of 10K bits per inch and a 5 inch track radius, 99 sectors would result in 384 bytes per sector. Correspondingly, with 5% of the total disk area allotted to position servo information and 99 sectors, each servo sector would be 15.8 millinch long. However, data blocks of .95 * 384 = 364 bytes are too short for good efficiency; block lengths of 512 or 1024 bytes would be much better, especially when error correction codes are considered. A 15 millinch servo sector is also difficult to work with because after the space required for a reliable sector mark or sync field is subtracted, there is little length remaining for a position signal encoding that has both good accuracy and noise immunity. For these reasons reducing the number of sectors from 99 by a factor even as small as 3 would be very desirable if it were possible to concurrently maintain good servo loop dynamics. Several aspects of the overall positioning system which are relevant to the effect of sampling on servo dynamics can be examined by means of block diagrams.

Fig. 2 illustrates the positioning servo system with a continuous position signal; the open loop transfer function is G and closed loop $X_H/X_T = G/(1+G)$. Sectorizing the position signal adds a sample and hold function to the forward path as indicated in Fig. 3; the open loop transfer function is then $G' = GT_s$ and closed loop $X_H/X_T = GT_s/(1+GT_s)$. Viewed in the time domain, the limitation of the sectorized servo loop is lack of head position information during the time interval between sectors. If a source of wide band head position information were available during this time interval, it could greatly improve loop dynamics even if it were referenced to the base plate rather than the data track. Such a signal can be obtained by integrating the carriage velocity signal available from the tachometer used in the track accessing servo, provided the integrator is reset to zero at each sector so that its dc drift will not be accumulated. This configuration is described by Fig. 4. If the integrator gain is properly calibrated, the open loop transfer function is G and closed loop $X_H/X_T = GT_s/(1+G)$. With this integrator gain, Fig. 4 can be algebraicly rearranged to the equivalent but more easily interpreted form of Fig. 4'.

Comparison of Figs. 2 and 4' clearly shows that the loop transfer functions and thus loop dynamics of the sectorized system are the same as those of a continuous system, and effectively only the command or track position signal is sampled. In order to directly compare the corresponding time responses, the systems of Figs. 2, 3, and 4' were simulated using the open loop transfer function G of equation (1) with $w_c = 1$, $w_r = (w_c/5.5)$, and N = 33 and 99. Their response to a unit step and a unit sinusoid of frequency $w_r$ are shown in Figs. 5, 6, and 7.

From these figures it can be seen that the position error in following runout for a 33 sector servo with supplementary position signal is about 16% as opposed to 9% for a continuous system, and 24% and 20% for 33 and 99 sector servos respectively when supplementary position signal is not used.

In summary, present disk file head positioning servos cannot provide sufficient accuracy for increased radial track density because of mechanical tolerances between the servo head and data heads and servo disk and data disks which are outside the servo loop. These tolerances can be put inside the servo loop and thus effectively minimized by using a sectorized track following servo which has position information in sectors on each of the data surfaces. When supplementary position signal from the carriage tachometer is included in the sectorized servo, satisfactory performance can be obtained with as few as about 30 sectors on each surface.

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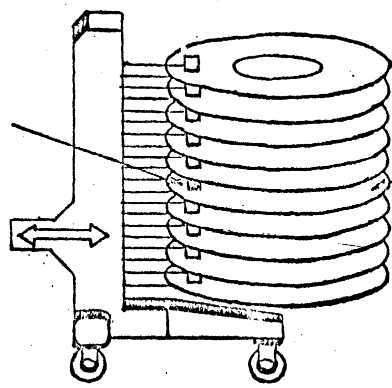


FIG. 1. 3330 POSITIONING SYSTEM

1. SPINDLE ECCENTRICITY
2. SPINDLE TILT
3. T-BLOCK TILT (IN PLANE OF ACCESS)
4. T-BLOCK TILT (⊥ TO PLANE OF ACCESS)
5. HEAD ADJUSTMENT ACCURACY & STABILITY
6. DISK AND CARRIAGE VIBRATION
7. TEMPERATURE (DIFFERENTIAL EXPANSION)
8. BEARING-WAY WEAR

TABLE 1. POSITION TOLERANCE SOURCES

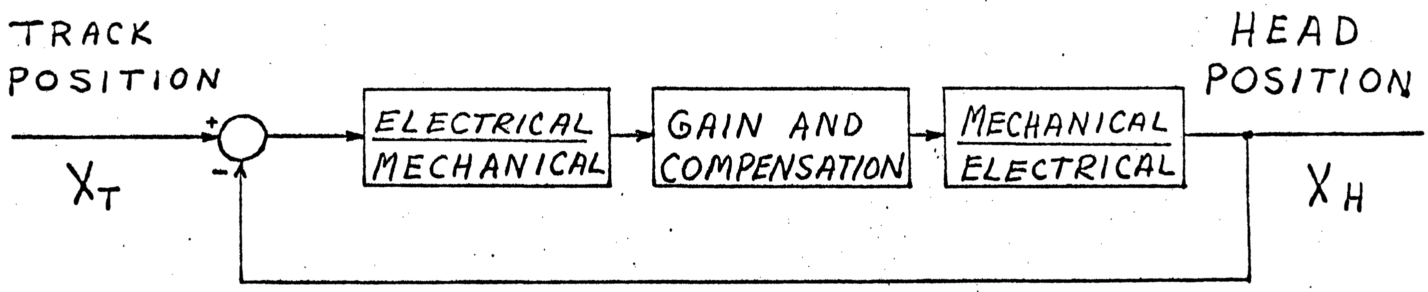


FIG 2. STANDARD SERVO, CONTINUOUS POSITION SIGNAL

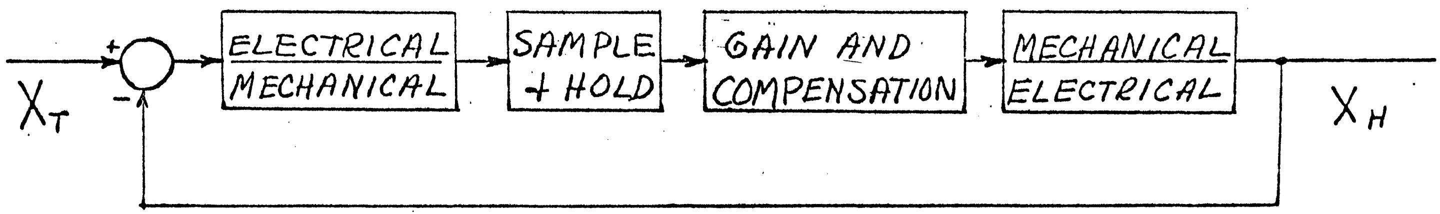


FIG 3. SECTORIZED SERVO

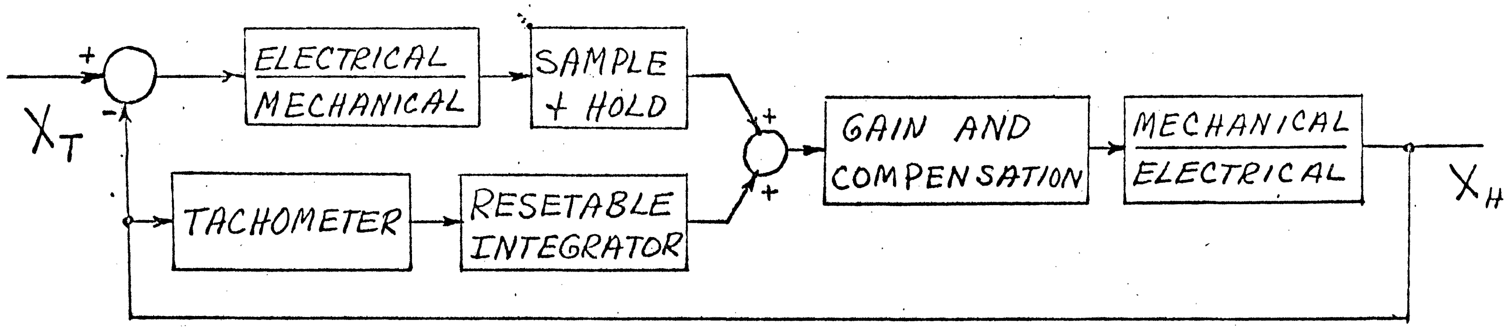


FIG 4. SECTORIZED SERVO, SUPPLEMENTARY POSITION SIGNAL

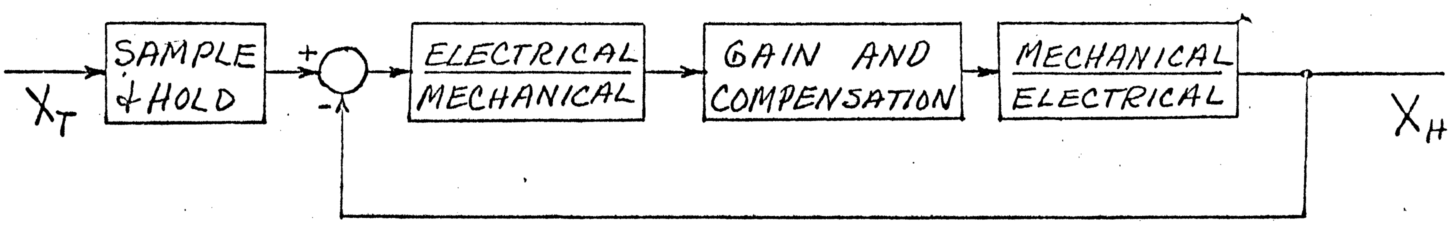


FIG. 4'. EQUIVALENT REPRESENTATION FOR FIG.4

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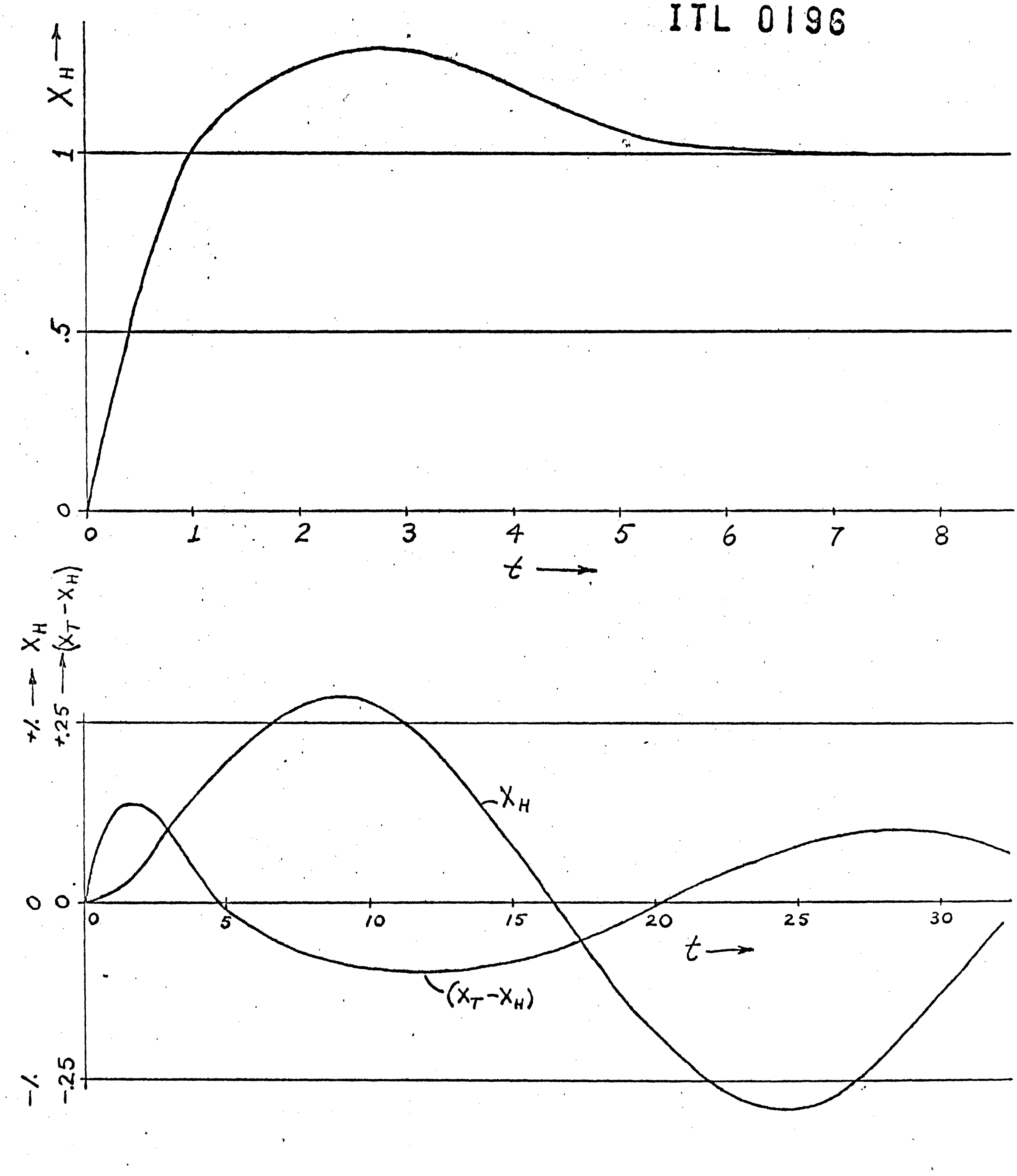


FIG. 5 RESPONSE FOR SYSTEM OF FIG. 2

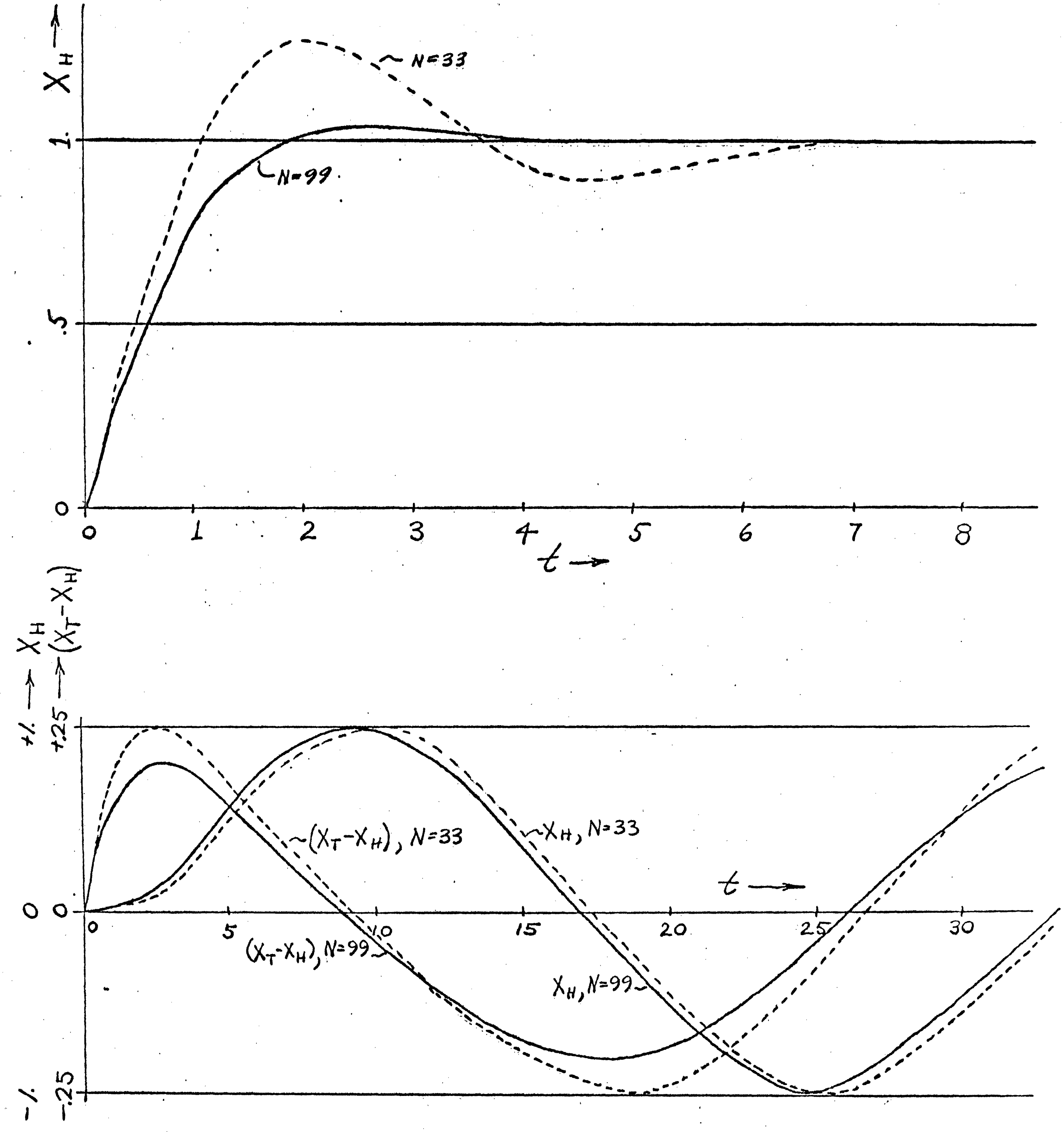


FIG. 6 RESPONSE FOR SYSTEM OF FIG. 3

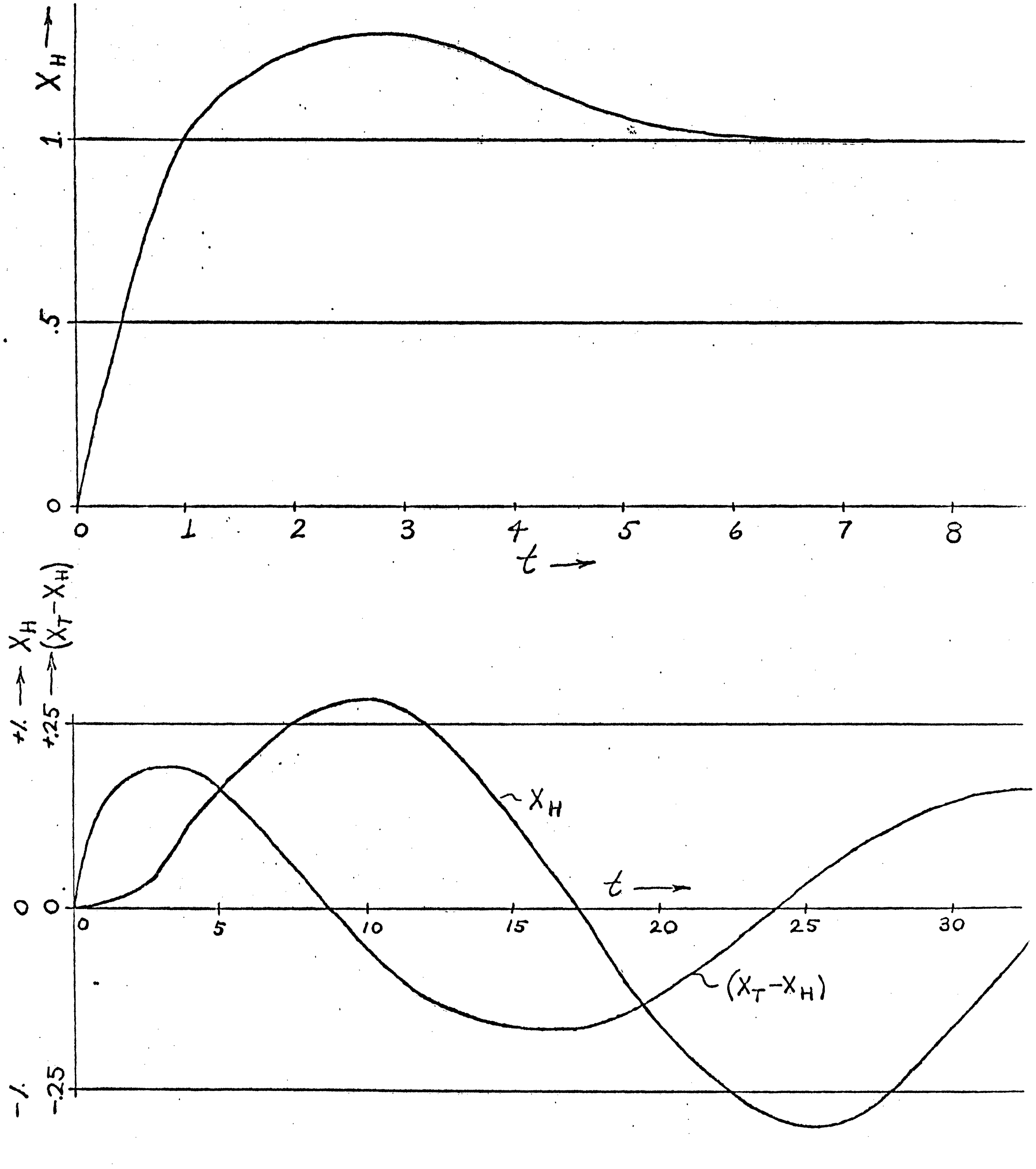


FIG. 7 RESPONSE FOR SYSTEM OF FIG. 4', N=33