# HARMONIC DISTORTION OF THE REFERENCE WAVEFORM

## Common Signal Distortion

Tracking type Synchro to Digital converters are not sensitive to distortion of the reference waveform, very large distortions like 20% third harmonic will have negligible effect on the working of the converters. Distortion of the reference will alter the internal loop gain of the converter, but since the type 2 servo loop is employed in all the tracking converters very large loop changes can be tolerated without errors being caused.

The following analysis shows the way in which distortion of the reference waveform is of no practical consequence.

If there is distortion on the reference the resolver form signals can be represented by:

$$\text{Sin}\ \phi \sum_{n=1}^{n=N} B_n\ \text{Sin}.(n\omega t + \alpha_n)$$

and

$$\text{Cos}\ \phi \sum_{n=1}^{n=N} B_n\ \text{Sin}.(n\omega t + \alpha_n)$$

where $\phi$, is the resolver angle, $\omega = 2\pi f$, where f is the reference fundamental frequency with $B_n$ and $\alpha_n$ as the harmonic amplitudes and phases.

The operation of the tracking control loop is to multiply the resolver form signals by Cos $\theta$ and Sin $\theta$ respectively, where $\theta$ is the RDC output angle. They are then subtracted and the result is applied to a phase sensitive detector to produce the control loop error signal. The error signal is reduced to zero by the action of the control loop. Carrying out these operations in steps we have:

$$\varepsilon_1 = \text{Sin}\ \phi \sum_{n=1}^{n=N} B_n\ \text{Sin}.(n\omega t + \alpha_n).(\text{Sin}\ \phi.\text{Cos}\ \theta - \text{Cos}\ \phi.\text{Sin}\ \theta)$$

$$\varepsilon_1 = \text{Sin}\ \phi \sum_{n=1}^{n=N} B_n\ \text{Sin}.(n\omega t + \alpha_n).(\text{Sin}\ \phi - \theta)$$

where $\varepsilon_1$ is the error signal before the phase sensitive detector.

Then:

$$\varepsilon_1 = \text{Sin}\ \phi \sum_{n=1}^{n=N} B_n\ \text{Sin}.(n\omega t + \alpha_n).(\text{Sin}\ \phi - \theta)$$

where $\varepsilon$ is the error after the phase sensitive detector and integrator.

The summation part of the above equation i.e.

$$\sum_{n=1}^{n=N} B_n \int_{\omega=0}^{\omega=\pi} \text{Sin.}(n\omega t + \alpha_n).\, dt$$

is just a constant, it will change in value according to the harmonic content but the important point is that this gives rise only to a change of loop gain and for the type 2 loop no errors will be caused by very large changes in this factor.

## Differential Distortion

While distortion of the reference waveform is of little consequence, since it occurs on *both* the sine and cosine channels, distortion of one channel only has a very different effect. In practice there is no reason why the carrier on the sine channel should be distorted differently from that of the cosine channel. It could be that amplifiers giving distortion are being used in which case it is worth knowing the effect of the differential distortion. Differential distortion does produce errors.

The following simple analysis shows the effect of 1% third harmonic (in phase with the carrier at $0^0$) added to the sine input with the cosine input undistorted.

Let the input signal be:

$\text{Sin}\ \omega t\ \text{Sin}\ \phi + K\ \text{Sin}\ 3\omega t\ \ \text{Sin}\ \phi$ (Sine input)

$\text{Sin}\ \omega t\ \text{Cos}\ \phi$ (Cosine input)

As before the operation of the converter is to multiply the sine input by Cos $\theta$ and to multiply the cosine input by Sin $\theta$ to subtract them, pass them through a phase sensitive detector and integrate the output to produce the error signal. Fig. C-1 shows the system and the equations for the voltages at the different points.

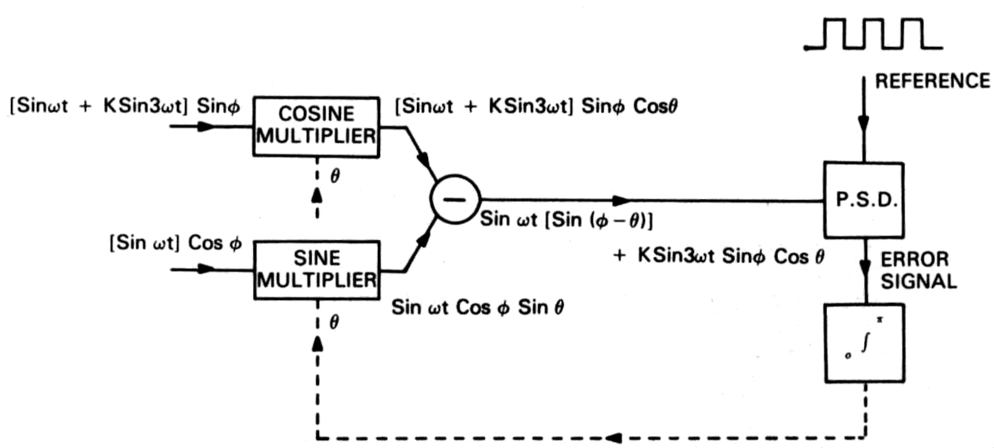


**Fig. C-1** The effect of differential distortion on Sine Channel only.

(1) Assume $\theta \approx \phi$ due to the feedback.

(2) The error is caused by the second term of the output from the subtractor and for $\theta \approx \phi$, $\text{Sin}\phi\ \ \text{Cos}\theta$ has a maximum of 0.5 for $\theta \approx \phi = 45°$.

(3) For $\theta \approx \phi = 45°$. the signal into the PSD is:

$\text{Sin}\ \omega t\ [\text{Sin}\ (\theta - \phi)] + 0.5\ K\ \text{Sin}\ 3\omega t$

(4) The output from the PSD is integrated and reduced to zero by the control loop.

(5) To simulate the effect of the PSD, integration is carried out only over one half period of the carrier. Due to the phase reversal of the PSD the other half period will be the same.

Writing

$$\phi - \theta = \varepsilon$$

$$\text{Sin}\ \varepsilon \int_0^\pi \sin \omega t\ d\omega t + 0.5K \int_0^\theta \text{Sin}\ 3\omega t\ d\omega t = 0$$

or

$$\text{Sin}\ \varepsilon\ [\text{Cos}\ \omega t]_{\omega t = 0}^{\omega t = \pi} + 0.5K\ [{}^1/_2\ \text{Cos}\ 3\omega t]_{\omega t = 0}^{\omega t = \pi} = 0$$

which gives:

$$2\ \text{Sin}\ \varepsilon + K/3 = 0$$

and for $\varepsilon$ in radians and $\varepsilon$ small

$$\varepsilon = -\ K/6$$

For example if K = 0.01 (1 % third harmonic)

$$\varepsilon^0 = 0.01/6 \times 57 = 0.095°$$

The conclusion here then is that differential harmonic distortion does have a considerable effect on the accuracy of the converter. Fortunately the areas where it is likely to occur are within the converters themselves, and care has been taken in the design to avoid errors due to this cause.