On Making Accurate Measurements with a Harmonic Distortion Meter*

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Summary—It is pointed out that an avoidable error occurs in making total harmonic distortion measurements by the usually recommended method with an instrument incorporating an average-responding output meter. The error arises from the fact that the average value of a full-wave rectified distortion signal can be reduced by adding a small phase-shifted fundamental component to the distortion. The error is always in the direction to make equipment seem better than it actually is and can amount to ten per cent or more It can be readily avoided by changing the instrument operating procedure.

THE rms harmonic distortion of a complex periodic waveshape may be defined as[1]

$$D_h = \frac{\left[\sum_{i=2}^{\infty} e_i^2\right]^{1/2}}{\left[\sum_{i=1}^{\infty} e_i^2\right]^{1/2}},$$

where e_i is the effective value of the ith distortion component and e_1 is the effective value of the fundamental. Sometimes the denominator is given as e_1 only,[2] but the above form is that best adapted to measurements of total harmonic distortion.

The quantity D_h may be calculated directly from measurements of the individual harmonic components e_i using a heterodyne type of wave analyzer. Here, however, we are concerned with the direct measurement of D_h using a total harmonic distortion meter.[2] With such an instrument, the rms value of the complex waveform [the denominator of (1)] is first measured or its indicated level set to a fixed value, then the fundamental component is eliminated by means of a tuned bridge, bridged T, parallel T, or other method, and the rms value of the remaining distortion components measured. If the original level is set to a reading of 100, then the second reading yields D_h directly in per cent.

The errors which are discussed here arise from the usual failure to employ true rms reading meters in commercial total harmonic distortion instruments. Instead, the general practice is to use meter scales calibrated in rms values, but meters which themselves respond to the average value of the full-wave rectified waveshape. The first error arising from this practice is well known—true rms readings are not obtained for complex waveforms. The size of the error depends on the specific waveform measured; for example, for a signal containing 20 per cent third harmonic, the maximum error from this source is 6.7 per cent.

The second error is more insidious. The usual instructions for the use of a total harmonic distortion meter call for the fundamental-eliminating circuit to be adjusted or balanced by varying the controls to give a minimum reading on the output meter. Generally, this minimum reading is then taken to be the per cent total harmonic distortion. This procedure would be strictly correct if a true rms reading output level indicator, such as a thermocouple or square-law VTVM, were used. It is incorrect when an average-responding output meter is used.

The reason the above procedure is incorrect when an average-responding meter is employed is that it is possible for the average value of a complex waveshape containing no fundamental to be reduced by the subsequent addition of a small amount of fundamental component. On the other hand, such addition increases the rms value. The above procedure of tuning for a minimum using an average-responding meter therefore involves tuning not for complete elimination of the fundamental, but, instead, tuning for the amount of fundamental which makes the resulting average value a minimum and less than the value which would be obtained with no fundamental component. This conclusion can be readily verified by observing the output of such a distortion meter before rectification and noting the presence of a fundamental component when the meter reading has been minimized.

The actual amount of the error arising from the above cause depends on the form of the distortion and upon the specific method of fundamental component elimination. Measurements made by the author with a commercial instrument, which employed a Wien bridge with feedback for fundamental elimination and an average-responding output meter, showed that the difference in readings between the minimum obtainable reading and that found when the fundamental was completely eliminated often amounted to ten per cent or more in the total harmonic distortion range from 0.5 to 10 per cent.

Because fundamental-elimination can be carried out in a number of ways for each of which the above type of error will vary, it is impractical to treat it mathematically even for the simple case of pure second harmonic distortion. We have, however, established the following results. When a small fraction of the fundamental, $\epsilon \sin \theta$, is added to a second harmonic term, sin

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[1] F. Langford-Smith, "Radiotron Designer's Handbook," Amalgamated Wireless Valve Co., Ltd., Sydney, Australia, 4th ed., p. 609; 1952.
[2] F. E. Terman, "Radio Engineers' Handbook," McGraw-Hill Book Co., Inc., New York, N. Y., p. 944; 1943.

2θ or $\cos 2\theta$, the average value of the full-wave rectified sum is a monotonically increasing function of ϵ as ϵ increases from zero. For this simplified case, the meter reading would, therefore, be that with zero fundamental component. Unfortunately, the experimental case is always more complex than this. Even with only pure second-harmonic distortion as the instrument is tuned away from the point of zero fundamental transmission, both ϵ and the phase of the injected fundamental component will vary. At the same time, the amplitude and phase of the second harmonic (and of any higher harmonics if they are present) will also vary, although such variation will be essentially negligible compared to that of the fundamental. Neglecting this latter variation, the calculation of the full-wave average value of $|\sin 2\theta + \epsilon \sin (\theta + \psi)|$ turns out to be exceedingly complex for even the Wien bridge case since both ϵ and ψ vary as the bridge is unbalanced.

What then can be done to use a total harmonic distortion meter with maximum accuracy? The best and obvious answer is to eliminate both of the kinds of errors we have discussed by using an rms-responding output indicator. When this is impractical, the second type of error can still virtually be eliminated in the following way. Instead of applying the distorted waveshape from the output of the device being measured to the distortion meter and tuning for a minimum, use a low-distortion, stable oscillator and first apply its output directly to the input of the distortion meter. Then tune the instrument to eliminate the fundamental. Here, it is allowable to tune for a minimum, since the distortion of the oscillator has been assumed very low; alternatively, the output of the distortion meter may be monitored with an oscilloscope and the tuning for fundamental elimination aided thereby. Next, the oscillator output is connected to the device to be tested and its output applied to the distortion meter input. First, the level of the complete waveform is adjusted to give a fixed reading on the (average-responding) output meter, say a reading of 100. Then, without readjusting the fundamental elimination circuit, the instrument is switched so that the fundamental is eliminated and the resulting percentage harmonic distortion is read on the output meter. If then the controls of the fundamental-eliminating circuit are readjusted for a minimum reading, it will be found that this reading is appreciably lower than the first more accurate reading, because a small amount of fundamental signal component has been added to the distortion components. This error is particularly insidious and is to be avoided in high-quality audio work because it always makes the device being measured seem better than it is in actuality.