CLARKE-HESS MODEL 5002

PHASE VERIFICATION BRIDGES

DESCRIPTION

The Model 5002 Phase Verification Bridge set are passive devices that are used in conjunction with Model 5500-2 Phase Standard and an output null indicator such as a true rms voltmeter, an oscilloscope or a wave analyzer to verify that the Phase Standard is continuing to operate within its specified phase accuracy limits. Each bridge has two input terminals for the two output terminals of the Phase Standard and an output terminal to which the null indicator is connected. An impedance (a resistor or a capacitor) is connected between each input terminal and the output terminal. The set comprises four bridges:

(1) **5002A. A one-to-one resistive bridge.**
Nominal loading of 50kW at its two inputs at balance. Usable from 1Hz to 50kHz. Inherent phase error less than ±1m° to 1kHz and ±2m° to 50kHz.

(2) **5002B. A one-to-one capacitive bridge.**
Nominal loading of 900pF at its two inputs at balance. Usable from lkHz to 200kHz. Inherent phase error less that ±2m° from 1kHz to 50kHz and less than ±8m° to 200kHz. (May be used below lkHz if special precautions are observed)

(3) **5002C. A ten-to-one capacitive bridge.**
Nominal loading of 900pF and 90pF at its two inputs at balance. Usable from lkHz to 200kHz. Inherent phase difference from the Standard C Bridge between 5kHz and 50kHz is less than ±2m°.

(4) **5002D. A hundred-to-one capacitive bridge.**
Nominal loading of 1000pF and l0pF at its two inputs at balance. Usable from lkHz to 200kHz. Inherent phase difference from the Standard D Bridge between 5kHz and 50Hz is less than ±2m°.

In addition to the bridges, each set contains three interconnecting coaxial cables, an Instruction Manual and a set of data comparing the particular Bridge Set to the Standard Bridge set developed by Clarke-Hess.

OPERATION

A four arm bridge has a single generator, and at least two arms are adjusted to produce the minimum output. With the Phase Standard, two outputs exist with an adjustable phase shift between them. This means that two arms are sufficient for the bridge. The bridge can be balanced by adjusting the relative amplitude of the two generators and the phase angle between them. If the two impedance arms of the bridge have identical phase angles, the bridge will balance when the phase angle between the two bridge inputs is exactly 180°, and each input amplitude divided by the magnitude of the impedance connected to its input has the same value.

All of the bridges are designed and constructed so that the two impedances have identical phase angles over a broad range of frequencies.

Since, in general, the two adjustments are independent, the amplitude balance can be made and then the phase balance. In practice, the amplitude gradations available from the Phase Standard, even though they are often as small as 1mV, are not sufficient to allow an accurate amplitude balance. To solve this problem, each bridge includes an AMPLITUDE vernier which permits the adjustment of the amplitude between the amplitude settings of the Phase Standard. Since the trimmer is of the same impedance type as the main arm of the bridge, it adjusts the amplitude without causing phase shifts. The difference between the phase indication on the Phase Standard at balance and 180° is the phase error in the Standard plus any small error in the bridges. Usually an offset of 180° is entered into the Phase Standard and the phase indication at balance becomes the phase error.

Increased Measurement Resolution

When an rms voltmeter is used as a null detector, its internal noise (and sometimes the minimum amplitude before the display is forced to zero) prevent an accurate determination of the null position. This problem can be overcome by setting the offset at 180°, balancing the bridge as well as possible, entering a large negative angle into the Phase Standard and recording the rms output voltage, entering the same magnitude angle, only positive, into the Phase Standard and recording the rms output voltage and then utilizing the following formula.

Phase error = Θ [Vneg - Vpos] / [Vneg + Vpos]

where Θ is the magnitude of the large angle in degrees, Vneg is the rms output for the negative angular deviation and Vpos is the rms output for the positive angular deviation The Phase error is in degrees and has a resolution of a fraction of a millidegree.

CALIBRATION

When the magnitude of the impedances in the two arms of the bridge are equal, the calibration of the bridge is very straight forward and can be done at the same time the error in the Phase Standard is being determined. This is accomplished by first determining the phase error as described above and then, without adjusting anything, interchanging the two input cables to the bridge and determining the phase error a second time. As can be easily shown, *the sum of the two phase errors divided by 2 is the error in the Phase Standard and the difference of the two phase errors divided by 2 is the error in the bridge.* If there is no bridge error, both phase errors are the same and equal to the Phase Standard error. If there is no Phase Standard error, the phase errors are equal and opposite in sign and track the bridge as its position is reversed.

When the magnitude of the impedances of the two arms of the bridge are not equal, the bridge is calibrated by the comparison method. In this case, the bridge to be calibrated and a Standard Bridge having the same ratio of the impedance magnitude of both arms as the bridge under test, are connected in parallel to the same Phase Standard. That is, a "tee" is placed on each output of the Phase Standard and the two equal length cables connected to each "tee" are connected to the corresponding inputs of each bridge. Each bridge has its own rms voltmeter connected to its output. Both bridges are nulled and the Phase Standard is deviated to obtain the Phase Error of both bridges simultaneously. Since the Phase Standard component of both errors is the same, the difference of the two errors is the error of the bridge under test relative to the Standard Bridge.

STANDARD BRIDGES

A Standard Bridge is a bridge that is known to have the same phase angle for the impedances in both of its arms. When such a bridge is used with the Phase Standard, the entire phase error away from 180° is due to the Phase Standard. When such a bridge is constructed, it can be used as a standard to calibrate other bridges as discussed in the preceding section.
The two ways of obtaining two impedances with the same phase angles at a large number of frequencies is to match them or to select impedances with known properties. Clarke-Hess uses the former approach while the U.S. Air Force uses the latter.

The Air Force approach is to use variable air dielectric capacitors with dissipation factors less than 0.00001 in both arms of the bridge. (A dissipation factor of 0.00001 corresponds to an angle of 0.00057°.) Such capacitors were supplied by General Radio, Inc. Model 722D is a low loss air dielectric capacitor variable from 110pF to 1100pF. With one of these capacitors for each bridge arm, any desired ratio of impedance can be set up. The Air Force has used this bridge for calibrating over 200 Clarke-Hess Phase Standards which they have purchased over a 16 year period.

The Clarke-Hess approach is to obtain a large number of low dissipation, high quality multi-layer ceramic capacitors and match them for phase angle at a number of frequencies between 100Hz and 200kHz. Two 900pF capacitors matched in such a fashion are used in the arms of the Model 5002B bridge. Eleven 900pF phase angle matched capacitors ar e used in the arms of the Model 5002C bridge. Ten are placed in series to form the 90pF arm while a single one is used for the 900pF arm. Twenty 100pF phase angle matched capacitors are used in the arms of the Model 5002D bridge. Ten are placed in series to form the 10pF arm while ten are placed in parallel to form the 1000pF arm.

The capacitors are matched in a test jig which resembles a 1:1 capacitor bridge. A reference capacitor is placed in one arm and the capacitor under test is placed in the other arm. The Phase error is recorded at all frequencies of interest. Keeping the same reference capacitor, the procedure is repeated for a second capacitor, and so on. Capacitors with the same set of phase errors for the differing frequencies are matched. The fact that the loss and the dissipation factor of these capacitors is low, keeps the Phase error terms low and thus makes the matching reasonably straight forward.

Confidence in this procedure has grown over the years as the number of bridges produced, using capacitors from different manufacturers, all resulted in bridges which were essentially identical to the in-house reference bridge set, S/N 71. In particular, typical agreement was within 1m° from 100Hz to 50kHz and within 4m° to 200kHz. Bridges constructed in this fashion do indeed provided an intrinsic standard for measuring errors in phase angle.

Resistance Bridges

Capacitor Bridges become very high impedances at low frequencies (below 100Hz) and are subject to phase errors because of parallel resistance loss. Consequently, for low frequency phase measurements, bridges with resistive arms are superior. Because of unequal stray capacitance across the two resistors, the phase error in such a bridge increases with increasing frequency. (Low loss stray capacitance has no effect on the angle of a capacitor bridge). To make such a bridge essentially perfect, in the 1:1 case, a variable capacitor, in the form of a wire bent over the resistor with the lower amount of stray capacitance, is adjusted until the bridge has no error at 50kHz as determined by the bridge reversal method. With this adjustment, similar bridge reversal measurements at other frequencies always indicate that the bridge produces very little phase error. Very little error is also indicated when the 1:1 resistive bridge, Model 5002A is compared with the Model 5002B capacitive bridge.

NO STANDARD PHASE ANGLE

Unlike the standard meter and the standard Volt, there is no standard Phase Angle at any of the national laboratories. Because of this, one has to rely on the properly constructed bridge set as an intrinsic standard to verify the proper performance of phase generating devices at an angle of 180°. Because of the long history at Clarke-Hess of producing hundreds of Phase Standards and Phase Bridges, comparing each and every one of them with previously manufactured Phase Standards and Phase Bridges and finding the results with a very tight statistical error bound, Clarke-Hess has every confidence that any piece of phase equipment they produce is well within any published tolerances.