

Dynamic calibration of fatigue testing machines

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Abstract

This paper describes the dynamic calibration of fatigue testing machines. The principle of operation and the evaluation of the new NPL dynamic force standard for the calibration of fatigue testing machines are given.

Introduction

Many industrial force measurements are conducted in the field of material testing. Although standards for the characterisation of fatigue testing machines do exist [1], the instrumentation used for the characterisation of fatigue testing machines is not traceable to the national electrical standards. Most of the instruments used in the fatigue testing use sampling techniques. The calibration of these instruments is based on the peak and trough values of the measured signal.

The National Physical Laboratory (NPL) developed a dynamic force standard (DFS) to provide traceable measurements according to the BS 7935 [1]. The challenge in designing the DFS was to provide traceability for fatigue testing machines based on peak and trough voltage measurements. This paper describes the principle of operation and the evaluation of the DFS developed at NPL.

Principle of operation

The DFS (Figure 1) can be used to simulate the dynamic characteristic of strain gauge bridges. The dynamic simulation of strain gauge bridges is realised by applying suitable DC and AC signals at the output nodes of a balanced (or unbalanced) strain gauge bridge at specified input and output impedances of the bridge.

The BS 7935 is defined for one static and two dynamic tests for fatigue testing machines. In the static test DC signals are used and in the dynamic test (a) a single-frequency AC signal and (b) a multi-frequency AC signal is superimposed on a DC signal. While commercial fatigue testing machines operate at frequencies up to 200Hz, the BS 7935 defines frequencies up to 100Hz. Table 1 shows the magnitude and phase components of the multi-frequency AC signal used in the DFS.

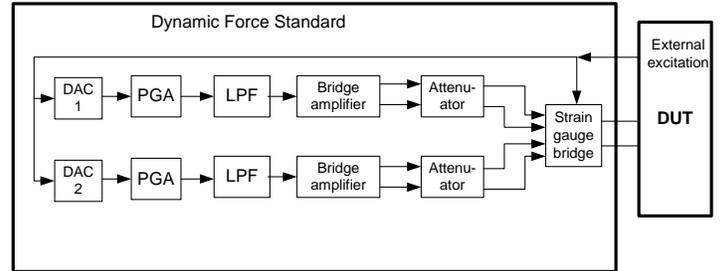


Figure 1: Dynamic Force Standard

Harmonic	Amplitude (% of fundamental)	Phase (degrees)
1	100	0
2	3	180
5	1.26	180

Table 1. Harmonic content of the multi-frequency DFS calibration waveform.

The DFS principle of operation is as follows. One DC and one AC signal are produced by two digital-to-analogue converters (DAC). The output of each DAC is passed through a programmable gain amplifier (PGA) and an anti-aliasing low-pass filter (LPF). The output of the LPF of each channel is applied to a bridge amplifier and the output of each bridge amplifier is connected to the output nodes of the strain gauge bridge simulator through a resistive attenuator. The attenuator resistors are used to sum the DC and AC signals produced by the DAC. As a strain gauge bridge simulator, four precision low-drift resistors were used. The current DFS supports strain gauge bridges of 350 Ω but can be modified to calibrate strain gauge bridges of 125 Ω and 700 Ω .

The system is designed as floating, i.e., the ground of the DFS is different from the ground of the instrument under calibration (DUT). The DFS contains two linear isolated power supplies from the mains and is controlled from the host computer via an optical ring. The excitation voltage of the strain gauge bridge (which is provided by the DUT) is

used as reference voltage of the DAC, so that the DFS operates in a ratiometric mode with the DUT.

Evaluation

For the static (DC) calibration of the DFS a digital voltmeter (Agilent 3458A) was used. The uncertainty of the DFS output to the nominal voltage specified by the BS 7935 is less than $5\mu\text{V}$, at DC, which is less than the uncertainty defined in the BS 7935 ($20\mu\text{V}$).

For the dynamic calibration of fatigue testing machines, the BS 7935 defines the output voltages of the DFS as peak and trough values. To obtain confidence on the calibration of the DFS under dynamic conditions, the output voltage of the DFS was measured by two different voltage measurement instruments (the NPL digital sampling wattmeter, DSWM, and the WAVETEK 4920, 4920) and the experimental results were compared with simulated results of a DFS model, the latter based on actual measurements. The DSWM is a data acquisition system that can provide information about the RMS, peak and trough values of the input signal while the 4920 can display only the RMS value of the input signal. To obtain a practical and reliable model for the DFS, the frequency response of the system was measured and a first order low-pass filter transfer function was used to approximate the measured frequency response.

Table 2 contains the percentage error between the RMS values of the (a) DSWM and the 4920, (b) 4920 and the simulation model and (c) nominal value between the values defined by the BS 7935 and the 4920 at five frequencies and four AC peak-trough output voltages as specified by the BS 7935. As can be seen from table 2, the difference between the two different measuring instruments and the error between the 4920 and the model are less than 0.1 %. The measurement uncertainty was better than 0.05 %. All the instruments used for the calibration of the DFS are traceable to the UK's national standards.

Discussion

The approach used to simulate the dynamic characteristics of strain gauge bridges of the DFS is simply based on the superposition of DC and AC signals to the output of the strain gauge bridge. The design of the DFS leads to a ratiometric measurement, the input and output impedance of the strain gauge bridge is slightly modified (e.g. less than 0.2 %) from the nominal by the DFS. The approach used in the DFS is simple to implement, does not require switching and the DFS can easily be modified to simulate strain gauge bridges of any value. The design of the DFS was based on the assumption that the DUT has infinite input impedance. If the assumption does not hold, corrections for the DUT input impedance must be applied. However, corrections for the DUT input impedance for the multi-frequency AC case can be difficult in implementation.

Conclusion

NPL has designed a dynamic force standard for the dynamic calibration of fatigue testing machines according to the BS 7935. Initial tests with commercial fatigue testing machines have been conducted and the recorded results are in agreement with the results shown in table 2.

Acknowledgements

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Reference:

BS 7935-2:2004 Constant amplitude dynamic force calibration-Part 2: calibration of device instrumentation to be used for the dynamic calibration of nonresonant uniaxial dynamic testing systems-Method.

f (Hz)	Vo (mV) peak-peak nominal	Error (%) DSWM/ 4920	Error (%) 4920/ model	Error (%) BS 7935 4920
17	40	-0.0439	-0.0169	-0.0605
	30	0.0106	0.0138	-0.0334
	20	-0.0091	-0.0171	-0.0599
	10	-0.0054	-0.0139	-0.0644
20	40	-0.0008	-0.0194	-0.0525
	30	0.0111	-0.0198	-0.0447
	20	-0.0041	-0.0196	-0.0477
	10	-0.0052	-0.0169	-0.0504
25	40	-0.0018	-0.0241	-0.0476
	30	-0.0004	-0.0247	-0.0380
	20	-0.0060	-0.0241	-0.0420
	10	-0.0079	-0.0335	-0.0473
50	40	0.0045	-0.0056	0.0425
	30	-0.0033	-0.0056	0.0486
	20	-0.0069	-0.0057	0.0513
	10	-0.0070	-0.0015	0.0605
100	40	0.0047	0.0910	0.4016
	30	-0.0049	0.0824	0.4136
	20	-0.0080	0.0834	0.4189
	10	-0.0100	0.0858	0.4120

Table 2 Summary of experimental results, single-frequency AC-case