Federation of Model Engineering Societies

Information Sheet No. 21

Date: January 2022
Subject: A note on Dead Weight testers, 'calibration' and Boiler Test Code (2018)

Origins.

This note began as a comment about an aspect of the boiler test code. It has subsequently been discussed with the Model Engineer's Liaison Group (MELG), which is the creator and manager of the test codes and documentation and ultimate authority on their meaning.

The reference to dead weight test apparatus appears in the 2018 revision of the Boiler Test Code (BTC) Vol. 1 at Clause 6.9, in Vol. 2 at Clause 9.1 and in Vol. 3 at Clause 11.1.

The MELG took the view that it was a useful and informative note on the interpretation of the current text of the test code and it was approved as guide for use by the members of the MELG.

It must be noted that this document does not mandate the use of Dead Weight Testers for the checking of pressure gauges. Dead Weight Testers are available and may be used but there is no requirement stated or implied here that any Society must use one. The alternative of calibration of a master pressure gauge by an independent commercial test facility remains an option.

Preamble.

Recently, the topic of 'validating' a dead-weight pressure tester (DWT), as required by the current Boiler Test Code 2018 (BTC) has arisen. This started with a query raised in a member Society's committee meeting about "calibrating" a dead weight tester. In subsequent correspondence, two members of that Society replied it was not necessary on the grounds that a dead-weight tester is a "primary" standard.

Subsequently, the Federation Safety Officer was also asked for clarification by a member of another Society, who also cited "confusion" in the BTC. That section mandates the use of either a "calibrated" test gauge or a "validated" DWT [author's emphasis].

Therein lies the source of the confusion – the distinction between "calibrated" and "validated".

Calibration *v*. validation.

The OED defines "calibrate" as "determine the calibre of; to graduate a gauge of any kind with allowance for its irregularities". It defines "validate" as "make valid or of good authority; to confirm, corroborate, substantiate or support".

The concept of a “calibrated” pressure gauge is fairly simple, at least superficially. A gauge can be sent to an approved test facility and is returned, in exchange for some money, with a certificate stating its reading errors relative to a traceable standard. The responsibility for accuracy thus appears to lie with the test facility. Actually, the ‘owner’ of the gauge also has a significant responsibility – to keep the gauge safe and secure and to record its usage. There may be subsequent damage to the calibrated device that renders the calibration invalid. For something like a Bourdon-type pressure gauge, dropping it would almost certainly do that. Overloading it definitely will. It is doubtful whether many member clubs or Societies are applying that degree of control, thus very likely rendering their calibration suspect anyway. However, it is still a relatively simple concept.

As a result, it is relatively easy to agree about the meaning of “calibration” in the BTC. The definition and use is in accordance with the common understanding of the word. It includes that essential element of “graduation” or measurement.

The alternative of using a DWT appears also to be simple, at least for those Societies that actually have access to one - they are quite expensive. In principle, it also is straightforward. The difficulties arise from the use of the description “validated” in the BTC.

The potential uncertainty was introduced by the drafters of the current BTC (the MELG). They chose to use the word “validated”, presumably with full knowledge of its meaning and its distinction from “calibrated”. The above definition of “validate” doesn't include that element of measurement and that’s the essential difference.

To put so much weight on a single word is, perhaps, not helpful for most users of the BTC. It is liable to cause disagreement and confusion.

Primary and secondary standards.

Primary standards are ones that will reproduce a value based only on the fundamental parameters of length, time and mass as internationally established. The value produced is dependent only on the basic parameters <u>and can be predicted accurately from them</u>. This of course is subject to the device remaining in good condition and being used correctly.

In the case of a DWT the dependency on mass is not quite absolute, but nearly so in the present context (see Sections below on “Primary Standards” and “DWT errors”).

Pressure gauges of the usual kind are only ‘transfer’ or ‘secondary’ standards to allow a primary determination to be convenient transferred to a different location or time. By their nature, they cannot produce an absolute measurement based just on their physical parameters and need to be calibrated against a primary standard, not the other way around.

Dead Weight Testers as primary standards.

The essential feature of a DWT is that the probable errors are not likely to change with age, use or environmental factors, as long as it is undamaged and used in accordance with the manufacturer's recommendations.

The value for pressure given by a DWT derives from the dimensions of the cylinder and the mass of the test weights, neither of which is subject to significant variation with time or use. It is true that the value does depend on the local value of gravity (not the actual mass of the ‘weights’) and gravity does vary a little (see Section below on “DWT errors”).

The fact is that a dead weight tester is a primary standard and, as such, does not need “calibration” in the normal sense of checking that it gives the correct value. A dead weight tester will always give a correct reading (within its own in-built limitations) as long as it is physically unimpaired and properly used.

DWT errors.

Traceability.

By definition, in order to be considered a primary standard, all measurements must be traceable to physical standards of mass and length and all errors inherent within the instruments must be either eliminated or evaluated. For a commercial DWT, the original manufacturers will have established that traceability for the device as originally supplied and will have supplied an original certificate of performance.

Measurement accuracy.

All measurement is ultimately limited in accuracy. In a DWT the diameter of the working cylinder will only be known to a limited accuracy and the effective weight will depend on the local value for the gravitational attraction. The former may introduce errors of the order of 0.02% and the latter ±0.003% over most of the UK, assuming the device is standardised for the UK.

Such errors are entirely insignificant for the amateur testing of model steam boilers, which are often designed with large factors of safety and always proof tested to 200% and then regularly tested to 150% of the design working pressure. Implicit in the BTC is the assumption that such errors are insignificant <u>for the purposes of the BTC</u>. Hence the use of “validated”.

Of course, a standards laboratory such as the UK National Physical Laboratory (NPL) would probably not regard such errors as insignificant for <u>their</u> purposes, which are quite different to those of the BTC. Then, a form of true calibration would be carried out. That would involve determining, as accurately as possible, the effective diameter of the working cylinder, the absolute value of the masses used for the dead weights and the local value of the gravitational constant. Then, a reference value for a standard pressure would be obtained. That would be checked against the internationally-agreed standard for pressure. In model engineering, we are not in that business. Neither does the NPL undertake the calibration of commercial DWTs.

It is interesting to note that the fundamental calibration of pressure is carried out at the NPL using a DWT. That is, in turn, traceable to SI through dimensional measurements of the components of primary standard. So the NPL uses the same form of DWT balance to determine the national standard for pressure. The only difference in the case of a commercial instrument is that it is not made to the same very close tolerances. However, providing that it is undamaged and used correctly, it will maintain the original manufacturer's specification. That is likely to be in the region of ± 0.02% maximum error (judging by current instruments on sale).

Error sources – dimensions.

For a commercial DWT, the cylinder diameter is determined at the time of manufacture and is accurate enough to define the accuracy of the original device as supplied - whatever that might be. It will be on the accompanying paperwork. The cylinder is unlikely to wear significantly in use and, if it does, the resulting leakage would be visible and inconvenient and render the device obviously suspect. Thus it would fail the ‘validation’ check'.

Error sources – mass of the testing weights and local gravity.

The dead weight masses are extremely unlikely to change unless bits get chipped off them or they get excessively dirty. Once again, they would fail the ‘validation’ check.

Another error source (if the tester is being used correctly) is the local force of gravity. That really does change with location and time. However, the general variation over the whole UK is everywhere less than ± 30mGal. That corresponds to errors in DWT pressure of ± 0.003% for the whole UK.

Error sources – vertical miss-alignment.

The final error source is the degree of vertical miss-alignment of the mass/cylinder assembly. Clearly, the actual force on the piston will be in direct proportion to the cosine of the error in the vertical alignment. Beyond a certain point, the device will not function correctly because of friction. In proper use, the masses must be 'spun' when supported by the fluid pressure. Any undue friction would at least cause an obvious lack of rotational freedom, if not a complete lock-up. That would also fail the 'validation' test.

Assuming the piston/mass assembly is quite free to rotate when lifted by the fluid pressure, potential errors from miss-alignment are tiny. A one degree levelling error would cause a 0.015% error in pressure. Levelling using even a really cheap spirit level would cause this error to be only 0.001% at most. These sorts of error are completely irrelevant for our purposes.

Error sources – Overall.

An estimate of the overall rms error for a commercial DWT, compared with its original test certificate is 0.0032%.

BTC (2018) and tolerances.

The older BTC (2012) gave no tolerances or requirements for the accuracy required of the "… checked and calibrated pressure gauge …". Errors of ±1% or even ±2% are surely inconsequential in the context of model boiler testing. Commercially-calibrated gauges are only verified to within 1%, unless special accuracy requirements are specified (at additional cost). Then ±0.5% or ±0.25% can be specified. It is unlikely that many of the gauges in common use could achieve and, more importantly, maintain those improved accuracies, especially when handled repeatedly and by untrained operators.

At such levels of precision, the gauges are also quite temperature sensitive. At significant additional cost, they can be calibrated for temperature as well. Thus, the specifications of the previous BTC were unlikely to achieve better than ±1% in any case, even for a so-called "calibrated" pressure gauge.

The 2018 edition of the BTC introduced a specified maximum tolerance of ±2% for the accuracy of the test gauge.

The long-term and repeatability error margins of a dead weight tester are practically certain to be less than ±0.1%. It is on this basis that a DWT, with maximum errors of very much less than ±1%, is deemed acceptable for the purposes of BTC (2018) as an independent standard for pressure testing providing that it has been assessed as undamaged and is being used according to the manufacturer's guidelines. Hence the use of the word "validated", i.e. "of good authority; to confirm, corroborate, substantiate or support".

This would not be true if errors of less than ±1% in boiler test pressures were required. Then, "validated" probably would not do and we would be in an entirely different ball game.

R. Walker
Safety Officer, Southern Federation of Model Engineering Societies.

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