Crane-hook measuring system simplifies production-floor weighing

by Eckhard Kranz

A large manufacturer of transformers needed a load-indication system which could: (1) handle capacities over 100 tonnes, (2) be implemented without great expense, and (3) be operated without obstructing production. The solution: Attach strain gages to the shank hook of an existing 120-tonne capacity overhead-traveling crane and process the signals with an amplifier also mounted on the crane hook. The amplifier includes an automatic taring device which permits zeroing at any time. Amplified signals are transmitted via sliprings to the cab where the weight is displayed digitally.

The modern power transformer is an extremely complex piece of equipment with numerous subassemblies made up of various different materials. Depending on their rated power, transformers can weigh up to several hundred tonnes. Manufacturers must be able to determine the weight of individual units for the user in preparing a suitable foundation for the equipment at the application site.

There are, of course, a variety of weighing methods available to industrial users, available both inside and outside the production facility. Choosing a system, however, can be complicated by the major factors of cost, available space, and load capacity. The following is a description of how a major transformer manufacturer with a complex set of weighing requirements — low cost, little space, high load capacity — solved its problem with a relative simple strain-gage application.

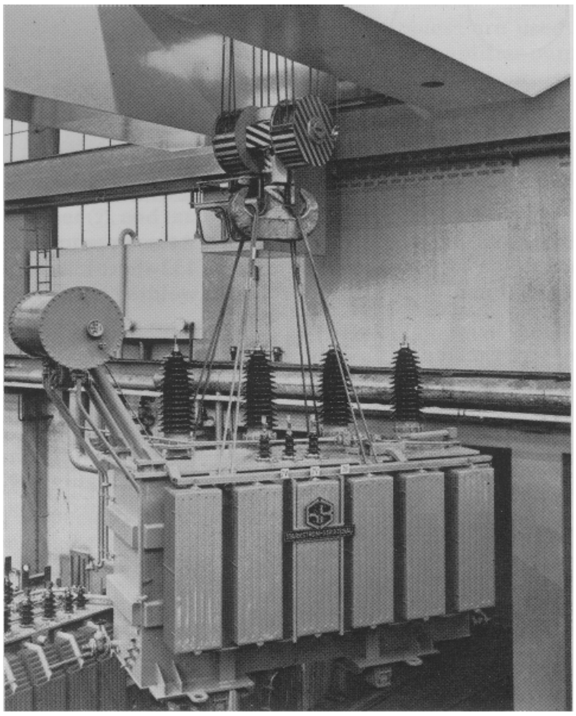

Fig. 1: Strain gages attached to crane hook were capable of providing adequate resolution, accuracy, and reproducibility for transformer weight determination

The firm manufactures power transformers ranging in size from 5 MVA to 100 MVA and built in subsections weighing as much as 100 tonnes (110 short tons). In the past, transformer weight had always been determined either from construction-material estimates or with the help of local railroad weigh stations. Both methods had major drawbacks however: Calculating the weight lacks reliability because of the internal complexity of the transformers; railroad weighing involves extra cost and provides only the weight of the complete unit, whereas the manufacturer and user are also greatly interested in individual weights of the main subassemblies.

In order to ameliorate the weaknesses of this system, a new weighing method was sought that could give intermediate values at the various stages of manufacture without interfering with normal production flow.

Platform scales and related techniques were quickly ruled out for space and cost reasons, and also because there was no way to accommodate them on the floor without obstructing the flow of production.

Conventional crane-based weighing methods, such as load cells, spring balances, etc., were deemed too expensive for the high loads expected, or were eliminated for other reasons.

Shank proves a reliable load indicator

Attention eventually turned toward the direct application of strain gages to a stressed part of the existing 120-tonne (132-ton) capacity overhead-traveling crane. The best place for this proved to be the shank of the crane's twin hook because the force exerted by the load acts axially on the shank, producing an almost constant strain over its cross section.

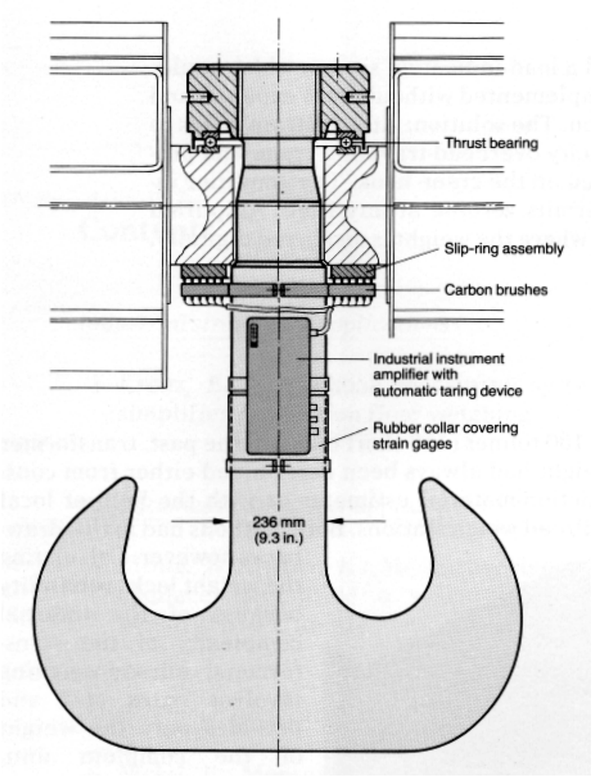

Fig. 2: Industrial-grade amplifier was attached directly to crane hook to reduce possibility of transmission errors between strain-gage circuit and display in cab

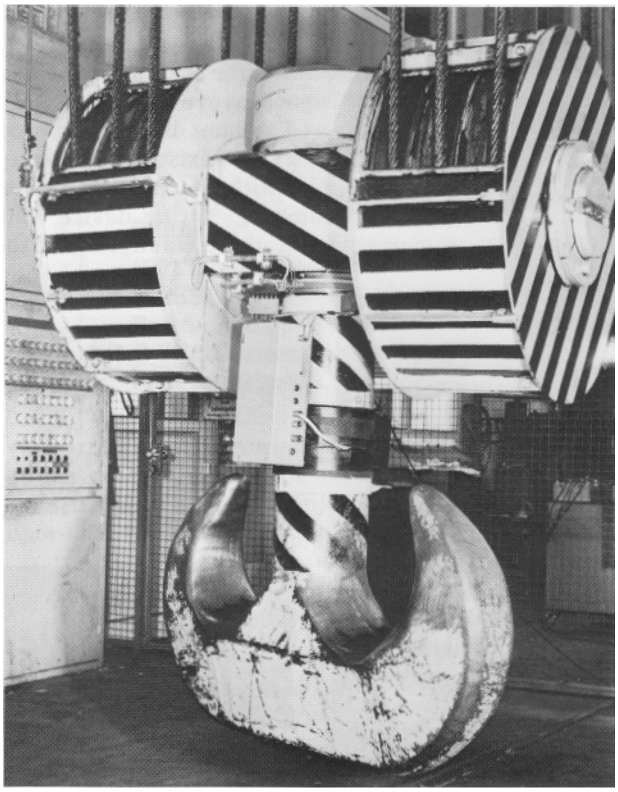

Fig. 3: Attachment of amplifier to crane hook of 120-tonne (132-short-ton) capacity did not involve any drilling or welding of the load-bearing parts

Under a nominal load of 120 tonnes (132 tons), the theoretical strain as measured at the hook shank should be approximately 130 µm/m — taking into account the shank diameter of 236 mm (9.3 in.) and a modulus of elasticity of 207,000 N/mm^2 (30 · 10^6 lb/in^2). The question remained whether this very low value of strain could provide adequate resolution, accuracy, and reproducibility when applying a Wheatstonebridge measuring circuit.

To test the proposed weighing method, two two-element 90-deg strain gages (HBM Type 3/120 XY 11) were attached to the circumference of the shank at 180 degrees to each other. This type of rosette contains two grids with measuring axes at right angles and must be specified with a thermal-expansion coefficient similar to the shank metal. Both gages are oriented so that the axis of one grid in each is parallel to the shank axis. The four grids of the strain gages are then connected in a full bridge. For the initial trials, output signals were processed by a single-channel 5-kHz carrier-frequency amplifier (HBM Type KWS 82.D7). This amplifier was calibrated (HBM Calibration Unit Type K 3607) on the basis of the theoretical strain created by the crane's nominal capacity so that the display would indicate load directly in tonnes.

In order to demonstrate the reproducibility of the strain signal and the zero stability of the display instrument, three transformers of different weights were lifted with the crane several times and the values before and after loading recorded. These tests demonstrated the satisfactory performance of the system. **Fig. 1** shows a power transformer with a rated power of 10 MVA and weighing 34.5 tonnes (38.0 tons) suspended from the crane during one of the tests.

Meeting practical requirements

Once the feasibility of the basic measuring method was proven, steps were taken to equip the crane with a measurement system suitable for normal everyday operation. The primary requirements included:

- Clear digital display in the crane cab, allowing the controller to determine weight within 0.1 tonne.

- Automatic zero setting before weighing, to compensate for any differences in cable weight.
- Immediate signal amplification at the crane hook, to eliminate transmission errors between the straingage circuit on the hook and the display in the cab, which can arise from long-term variations in contact resistance in the leads and slip rings. The signal must be transmitted to the display over a cable approximately 80 m (262 ft) long in conditioned form.
- Nonrestricted movement of the crane.
- Preservation of crane and hook integrity. In conformance with industry standards and equipment specifications, the attachment of amplifier, slip rings, etc. must not involve any drilling or welding of the load-bearing parts of the crane.

Because of the success of the weighing tests, the fullbridge measuring circuit already fitted to the crane hook was able to serve as the permanent sensing device. Although the measuring points were already adequately covered, a rubber collar was fitted around the shank over them to provide extra protection.

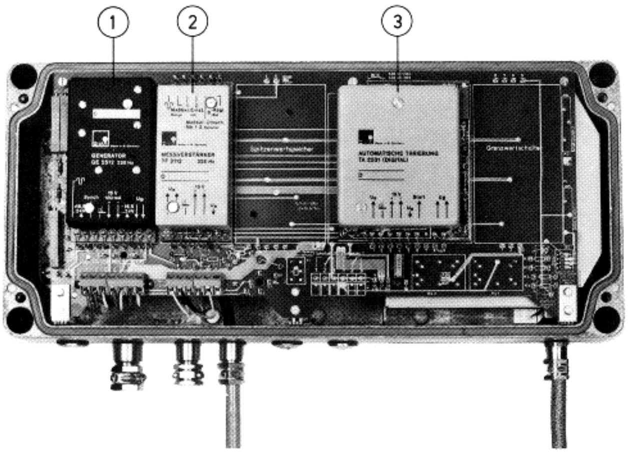

Fig. 4: Signal generator ①, amplifier ②, and taring unit ③ are housed in rugged cast housing well suited for application in industrial environments.

The strain-gage signals are processed by an industrialgrade instrument amplifier (HBM Type IG 2612 TA) which, although attached to the shank of the crane hook, is small enough to allow unhindered rotary motion. The placement of the measuring system on the hook is illustrated in **Fig. 2**, while **Fig. 3** shows the actual hook with the amplifier attached to the shank. The instrument amplifier [1] is specially designed for rugged industrial applications and for this reason is housed in a strong cast-metal case fitted with cableentry glands (see instrument description, page 19).

The amplifier uses a carrier-frequency of 225 Hz, which is especially suitable for strain-gage measurement, and incorporates a taring device which can be triggered by the closing of an external contact. The taring unit permits automatic zero-balance setting at any time so that the weight of the lifting cable on the hook can be compensated before the actual weighing begins. **Fig. 4** shows the opened amplifier case.

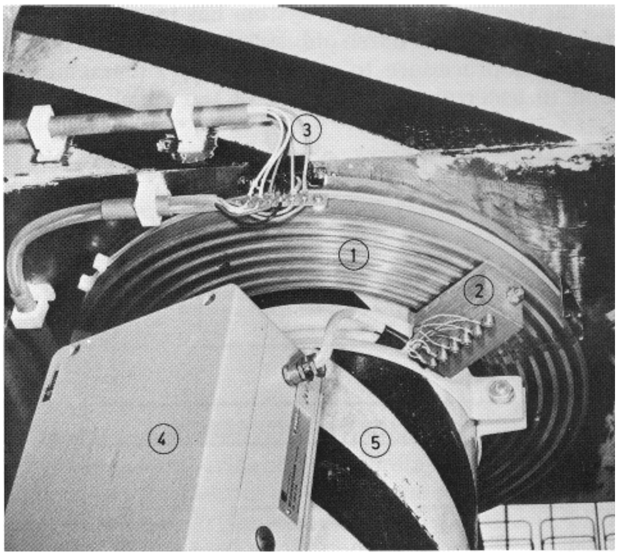

Fig. 5: Slip rings ① and brushes ② help in the transmission ③ of signal from amplifier ④, power supply, and zero-setting pulse between hook ⑤ and cab

Because the crane hook must be able to rotate freely about its vertical axis in the crossbeam, it is necessary to use a six-pole slip-ring assembly for signal transmission and power input. The slip-ring disk is attached to the crossbeam by means of surface-grip magnets. The slip rings, along which run soft carbon brushes, are made of medium-hard brass and are supported on a base of laminated fabric. A photograph of the slip-ring assembly is shown in **Fig. 5**.

Pairs of poless are used to transmit the 24-V power supply, the amplifier output signal, and the triggering pulse for the automatic taring device. When the crane hook is fully lowered, the transmission distance from the hook to a winding drum on the crane carriage is 11 m (36 ft). A 80-m (262-ft) long cable runs the distance from carriage and drum to the operator's cab via a second slip-ring assembly. In the cab, a digital display instrument (HBM Type DA 2401) indicates the load on the hook in tonnes. **Fig. 6** shows this digital display which is housed in a small case together with the pushbutton for triggering the automatic taring device. A block diagram of the system is shown in **Fig. 7**.

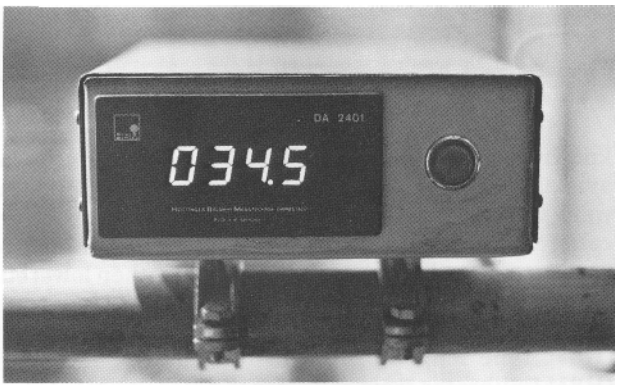

Fig. 6: Mounted in the cab is a weight display which includes pushbutton for automatic taring. Transmission distance between cab and hook is 80 m (262 ft)

So far the load-indication system has provided excellent service under harsh industrial conditions. It is now a simple procedure to weigh various subassemblies and to ascertain total weight of the finished transformers. The system is ready whenever the crane is brought into service. For the user, the method has proved to be a relatively inexpensive yet technically elegant solution to the problem at hand.

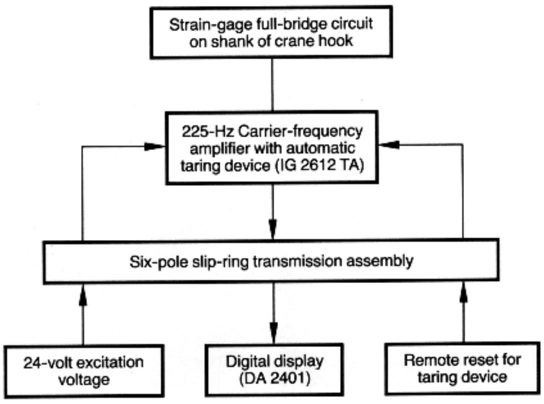

Fig. 7: Block diagram shows direction of information flow in strain-gage-based weight-determination system

Load cells aid in system calibration

The initial calibration of the load-indication system was based on calculation of the assumed axial strain under load at the measurement points along the shank circumference, factoring in the hook cross section and modulus. For practical weighing applications, however, the system had to be calibrated with actual known weights. Since no such heavy weights were available or could be procured, several transformers were weighed first with load cells and then used for calibration [2]. For the initial weighing, the transformers were lifted with hydraulic jacks and then lowered onto four load cells (HBM Type C1/30t). The load-cell signals were processed by an instrument amplifier (HBM Type KWS 82.D7) which had been calibrated (HBM Calibrator Type 3607) for the measurements.

Table: Transformer weights used in calibration

Transformer No.	Weight, tonnes (short tons)		Deviation*, %
	Load-cell system	Crane system	
1	74.13 (81.69)	74.1 (81.7)	0
2	44.54 (49.08)	44.3 (48.8)	0.2
3	18.03 (19.87)	17.9 (19.7)	0.1
4	10.93 (12.05)	10.9 (12.0)	0
5	1.57 (1.73)	1.6 (1.8)	0

* 120-tonne nominal load

The **Table** lists the results of individual weighings. Transformer No. 1, whose weights was measured with the load cells at 74.13 tonnes, was first used to calibrate the crane weighing system. The other weights listed in the table were used to check the linearity and accuracy in the lower weight range.

Error analysis

The crane-hook weight-determination system contains systematic errors caused by the inaccuracy of the calibration weights as measured with load cells and by inaccuracies in the measuring chain itself.

In order to estimate the inaccuracy of the calibration weights, the test certificates of the load cells used were evaluated and the errors of all elements of the load-cell-based measuring system calculated. Individually, these include the total error of the load cells $e_l \leqq 0.08\,\%$, the uncertainty of the calibrator $e_c \leqq 0.025\,\%$, the linearity error of the amplifier $e_a \leqq 0.05\,\%$, the linearity error of the digital display $e_d \leqq 0.02\,\%$, and a quantization error $e_q \leqq 0.01\,\%$. Thus, the probable error of the calibration weight e_w is:

$$e_w \leqq \pm \sqrt{e_l^2 + e_c^2 + e_a^2 + e_d^2 + e_q^2}$$
$$e_w \leqq \pm\, 0.1\,\%$$

For the inaccuracy of the actual weighing system, individual errors include the linearity error of the amplifier $e_{a'} \leqq 0.2\,\%$, the linearity error of the digital display $e_{d'} \leqq 0.03\,\%$, and a quantization error of one digit. Therefore, the probable error e_h of the system is:

$$e_h \leqq \pm \sqrt{e_{a'}^2 + e_{d'}^2} \pm 1 \text{ digit}$$
$$e_h \leqq \pm\, 0.04\,\% \pm 1 \text{ digit}$$

And the probable total error of the weighing system is:

$$e_{tot} \leqq \pm \sqrt{e_w^2 + e_h^2} \pm 1 \text{ digit}$$
$$e_{tot} \leqq \pm\, 0.11\,\% \pm 1 \text{ digit}$$

Allowing for the linearity check measurements at the crane hook, and the fact that the display resolution of the weighing system is restricted to 0.1 tonne due to vibration of the crane, it is possible to determine weight with a maximum error of 0.2 % at a nominal load of 120 tonnes.

References

[1] Rehkop, M., New concepts in industrial monitoring instrumentation: Industrial measuring instrument IG 2104 (only in German), Messtechnische Briefe 9 (1973), Vol. 3, pp. 50 – 52

[2] Determination of the center-of-gravity of a large transformer (in German), Messtechnische Briefe 4 (1968), Vol. 1, pp. 14 – 15

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