PROTOCOL

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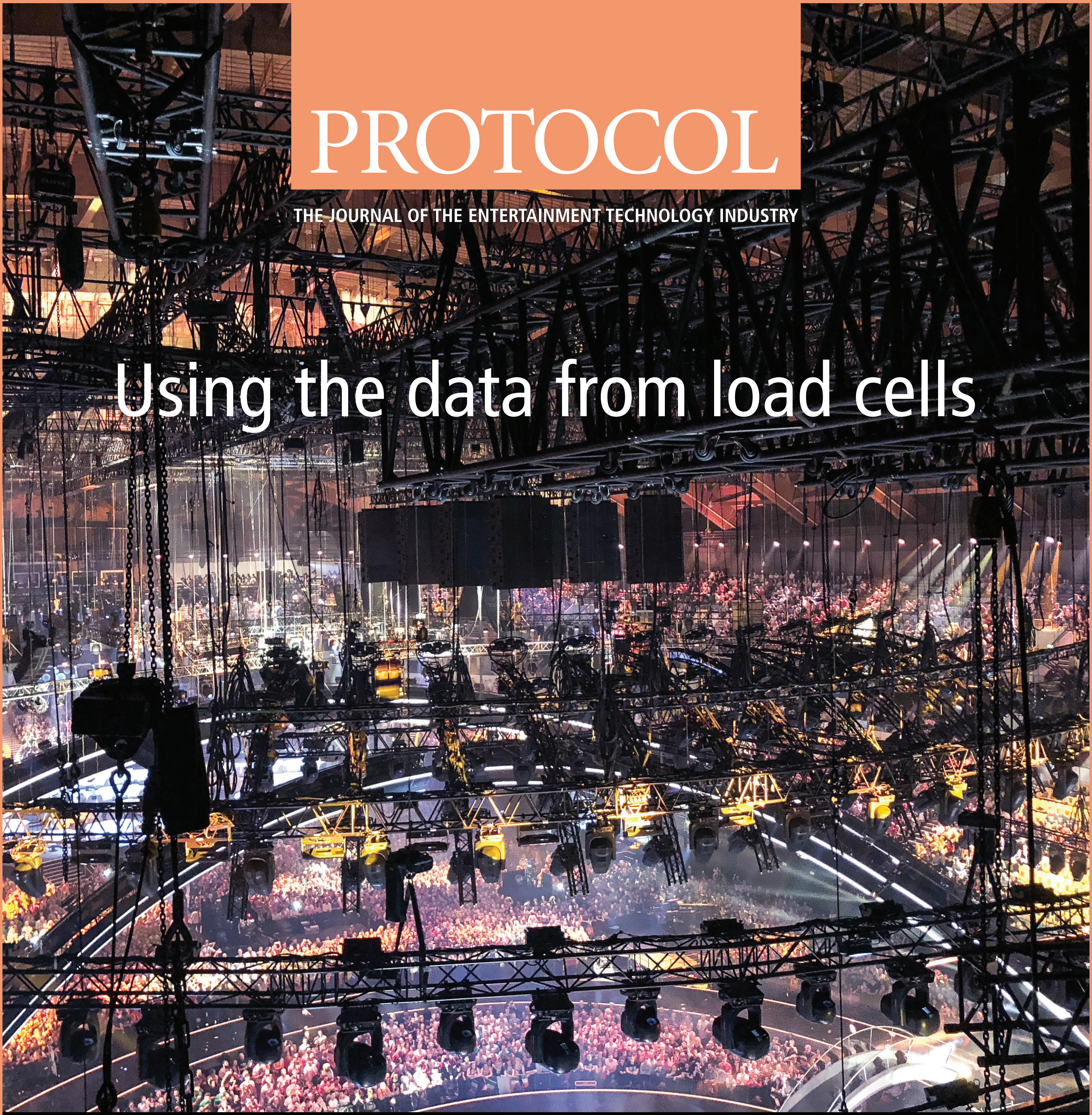

Using the data from load cells

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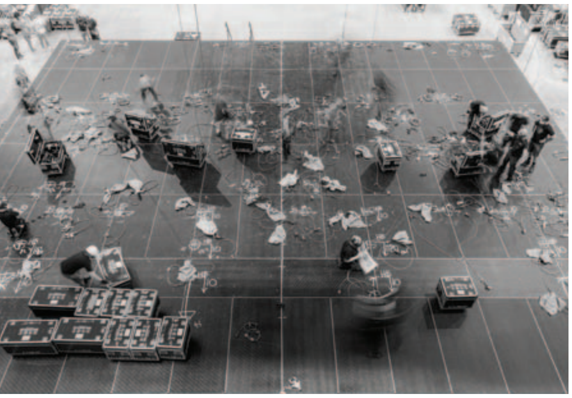

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Figures 1A and 1B – Odesza's 2022 *Last Goodbye* tour used 53 Broadweigh shackles to publish real-time load cell data to a website for access by all departments as needed. Data logging also allowed daily review of the data. Left is the stage at the start of load-in; right is the truss structure in the process of being flown.

Using the data from load cells

BY **TOM LILLY**

Introduction

IN A PREVIOUS ARTICLE (see the Summer 2020 *Protocol*) I discussed the inner workings of load cells and how they convert applied force into a useful measurement. This only scratched the surface of the subject of load cells, another major discussion point being, "Now I've got some load cell readings. What do I do with them?" One very important point about load cells is that they should be used as an aid for suitably qualified and experienced riggers, not as a substitute for them. Just putting load cells in a rig does not magically make it safe. It is important for a qualified rigger to watch the data and have a plan if the readings are not as expected.

There are many ways to safely and effectively use load cells and I don't presume to know them all. However, this article should give some further insight into how load cells can be used and where their limitations may affect the information available.

Usage

Static Weighing

This is by far the simplest and most common way to use load cells worldwide. Load cells are used every day in bathroom scales, weighbridges, shop scales, and many others. They are used here to find out an unknown weight. Loose load cells can be used for this as well, for instance, weighing interesting or unusual pieces of set.

To make good static readings, it is best not to rush. Allow the load to stabilise before taking a reading. Any swing will be obvious, but it is also possible that the load will be bouncing or vibrating as well.

Some of the larger touring shows do this in rehearsal to get a weight report to send to venues on the tour. This will require a complex system with multiple load cells and report generation. It can also be used to discover or prove the areas of concern that need permanent load cells for the duration of the tour.

Performer flying

As part of a risk assessment into performer flying, some riggers will want to carry out testing to discover the maximum loads experienced by the performer or the suspension points. This could be measured at a harness attachment point or where the ropes or silks et cetera are attached to a structure.

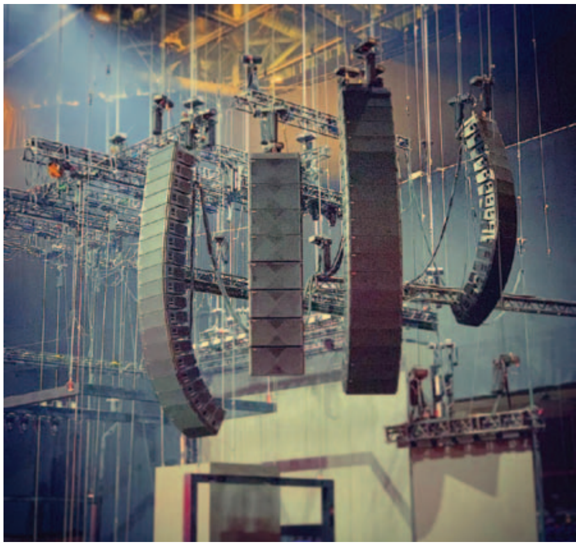

Figure 2 – 20 wireless load cells used at "pinch points" for the 1975 tour

Balancing a rig

When calculating loads for statically indeterminate structures, several assumptions need to be made. One of these can be that a truss is level. This sounds simple, but in reality it is difficult to achieve. Even if perfectly levelled at the ground, hoists can run at slightly different speeds, depending on age, length of power cable, and load being lifted. The only real way to know what the loads are on your points is to use load cells. You can then recreate the loads on your weight or engineering report.

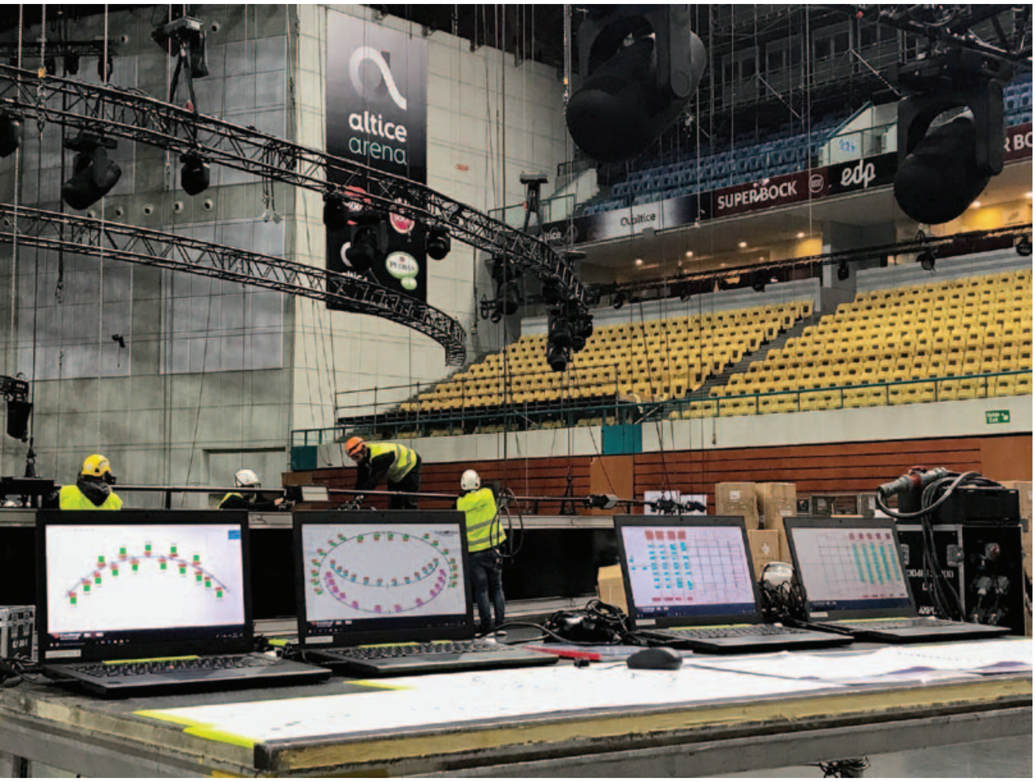

Figure 3 – Multiple laptops used to display data from more than 170 load cells at *Eurovision*

Monitoring a live lift

With more complex lifting operations it can be difficult to watch every single hoist and length of truss to make sure they are running correctly and not catching on anything. As an extra line of defence, it can be a good idea to have load cells monitoring the lift with alarms set to warn or even stop the operation if limits are exceeded (or communications are lost). These limits could be high limits showing that the end of the truss has been caught on the building, or low limits showing that the hoist has no load on it. This does not mean that you don't then have to watch the actual lifting operation. Real eyes are indispensable.

Proof-loading a system

When proof-loading a hoist or entire system, it is important to know what the actual applied load was. This can be achieved with known, calibrated weights, or calibrated load cells. Many large industrial cranes on docksides are tested with water weights. Load cells are especially useful in this instance to prove that you have collected enough (and not too much) water!

Wind loading

Putting load cells on guy wires of outdoor temporary structures can be very useful. It tells you that your initial tension applied was correct. (Tighter isn't always better!!). Also, when the wind gets up you can start to see the increase in forces in the whole system. This data, used with wind data, allows for better decisions on when to escalate a severe weather plan.

Shock testing

Another dynamic load, similar to performer flying, this could be testing the strength of safety bonds when a load is dropped onto them or seeing the increase in load as a hoist is started and stopped (or bumped).

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Considerations

There are a number of things to consider when using load cells. Here are a few of them.

Update rate

Digital systems talk about update rates (or similar). This is the rate at which the readings refresh and are transmitted. Some systems have a fixed rate which may limit their use or battery life. Others can be configured for the current use. If a system isn't changing very rapidly (weighing a single load for instance) then there is no need for an ultrafast update rate. However, if you are trying to measure shock loads, then a one second update rate will likely miss a large amount of important information.

Another important part of how the digital output is generated is the sample time. This is how long readings are taken before the average is taken to give to the output. The longer you do this for, the more background noise is averaged out, giving a more stable reading. Long sample times do decrease your battery life though.

Analogue systems don't take samples in the same way, they basically just amplify the signal (with some filtration to remove some noise). Because of this, they usually refer to a bandwidth that the load cell will respond well to. As you increase the frequency of input from DC you will get to a point where you are only getting half of the magnitude of reading. This is known as the 3 dB downpoint and is where the sensor becomes much less effective. This is usually in the region of kHz.

Display method

There are many display methods and there is no, single solution that will work for every situation. Handheld displays are easy and can be checked when wanted but may not have the nuances of PC logging and display software.

Most displays end up being limited by size and how much information you can fit on one screen. You probably don't want to attempt to carefully monitor 50 load cells from one single row display!

Fast update rates need different ways of dealing with the data. Monitoring dynamic loads at 100 Hz, you wouldn't be able to decipher anything useful just by watching a display. So, you either need to capture the peak value or log all the data on a PC to analyse later.

What happens on overload?

The first point here is that load cells do not know what will overload your system. The best they will know is what will overload them. However, a 3.25 tonne shackle load cell is often used with a one tonne hoist so the hoist will be overloaded long before the load cell. Some load cells have the limits set internally, others have the limits set in the display. There's no right way here, but it's important to know what your load cells do.

The simplest action on overload is an alarm. This then allows the human operator to make their own decision on whether to continue with the lift or not. In a basic system it is quite possible that the operator or chief rigger knows that there is a little headroom in the limits that have been set and so can continue. If possible, an early warning alarm is useful to let you know that you are approaching the ultimate limit and need to be ready to take action.

The alarm can be coupled with an automated emergency stop. If any load is detected over the threshold, then the hoist stops. However, care should be taken in the design of these systems. The most obvious point being that you may have to ensure that the whole lifting operation stops, not just one hoist. Also, if everything stops, can you then do anything to make it safe again? Some systems are designed so that you can only lower the load after an e-stop is triggered. There is not a one size fits all though! It is also worth noting that most industrial-based systems are not geared towards the entertainment industry.

Outside influences

Load cells are calibrated under repeatable test conditions. Real-life use is likely to be less than ideal and this will have an impact on the load cell's readings. Below are some of the more major ones. On their own, most of them won't cause more than one percent of full-scale error, but the cumulative effect can be worse.

Loading method

Most load cells are either calibrated in tension or compression. They will often

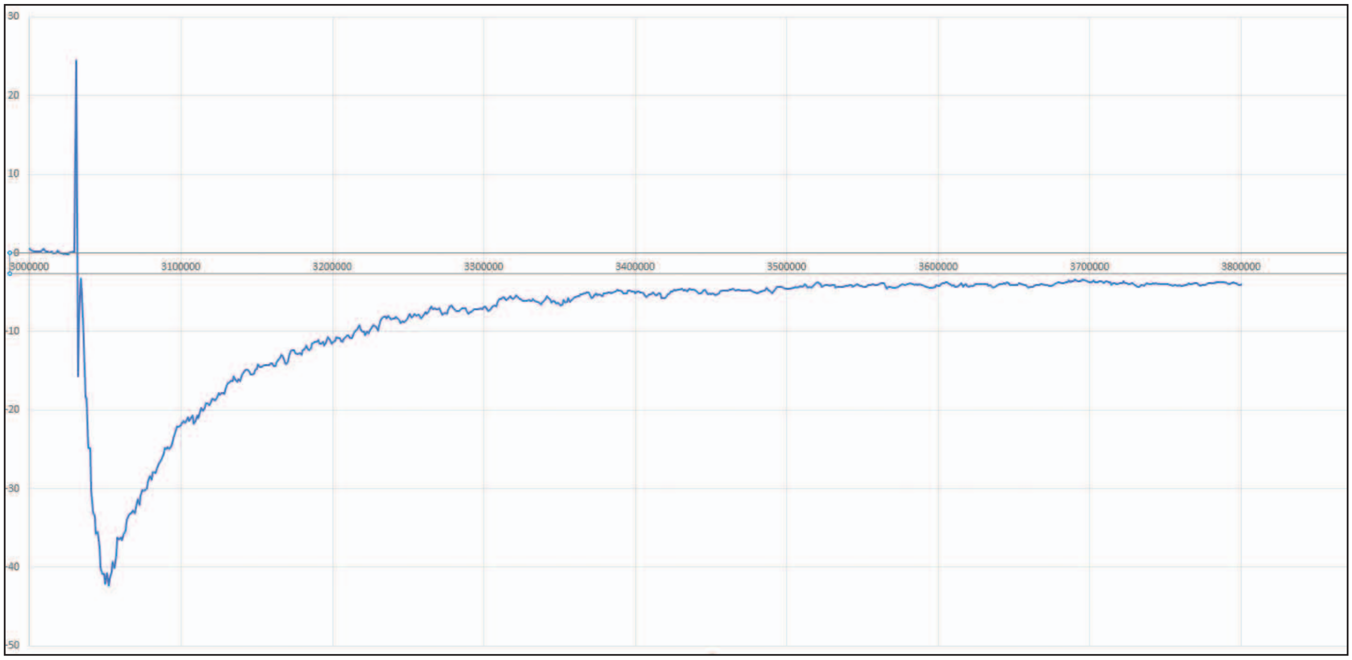

Figure 4 – Load pin cup of tea test results

work in the other mode but with a reduced accuracy. Also, a bending beam load cell will not measure the axial load.

Side loading

If the load cell is pushed off axis with a load perpendicular to the measured load, this will change the load measured. Additionally, if the load cell is designed for axial loads, this could cause damage.

Torsion

Any twisting will change the load measured by the load cell. You can see this by spinning the load on a single point below a load cell.

Out of axis loading

If the load path does not go straight through the load cell, then it is likely to give variations in measurement. Some load cells will right themselves up to a point, but if you can see it is not straight/level, the value will be less accurate.

Rapid temperature changes

To allow for temperature induced strain in a load cell, most manufacturers use strain gauges that are matched to the thermal properties of the load cell material. It is also possible to compensate for temperature using software. However, if there is a rapid temperature change, the inside and outside of the load cell will be at different temperatures and that will induce stress until the temperature has stabilised across the material. In a very basic (and not very well controlled!) experiment at home during lockdown I put a load pin in the freezer for an hour then took it out and put it in a cup of tea. See the graph in **Figure 4** which shows the load cell reading changing over time (in milliseconds). The zero-reading reduced by about 40 kg but returned to within 5 kg within ten minutes. Obviously, this is an extreme example that is unlikely to happen in real life. The most you are likely to see would be a 5 – 10 kg temporary deviation when moved from a cold truck into a warm venue.

Other factors

Creep

As I described in my previous article, materials such as steel deform in a fairly linear manner under increasing load until the yield point. You would imagine that a constant load will give a constant deformation. Unfortunately, this is not the case. There is a phenomenon called creep where deformation continues to increase with a constant load. Soft metals such as lead are particularly susceptible to this problem with sagging lead pipes on the outside of old houses being a well-known symptom. With load cells the effect is most noticeable immediately after dramatic changes in load and is normally relatively small (e.g. 0.05% of full scale over the first 20 minutes).

Figure 5 – Load cells used to monitor tension in Andrea Loreni's tightrope

Hysteresis

A load cell (in fact, any spring) will follow a different curve when the load is increasing than when the load is decreasing. Usually, the decreasing load will report a higher reading than the increasing load. This is known as hysteresis. This could be up to 1% variation.

Linearity

An idealised spring element will deform in a completely linear manner from zero load to full scale. However, in real life this is not ever quite the case. There are several solutions to this. A two-point calibration gives a best fit line to this curve. This means that compromises have to be taken with the accuracy. Alternately many load cell manufacturers use some form of multi-point calibration. This effectively divides the response curve into several straight lines giving a much better fit. The more points that you put in, the better the fit. For even

Figure 6 – Monitoring guy wire tension on an outdoor stage

Figure 7 – Using a smartphone to monitor loads

better accuracy, some manufacturers will use a polynomial curve to get a best fit curve.

Non-linearity is often at its worst as the load approaches zero.

Calibration

Load cells are sensitive technical equipment. Even if you look after them carefully it is possible that damage could occur, or components fail. You should always reality check readings and calibrate your load cells in line with the manufacturer's recommendation or your own risk assessment. This is typically every twelve months.

And finally…

Don't be complacent. Load cells don't make lifting safe all on their own. Where rigging is complex, engineers can tell you what you are meant to be seeing. Make sure that you know how your load cells are set up and that they are suitable for the purpose that you want to use them for. Test them before getting to site and you'll be in a much better position than going in blind. Load cells can be an incredibly useful tool for modern day riggers but you have to know what you are looking at! ■

Tom Lilly started in the entertainment industry more than 25 years ago carrying speakers and amplifiers upstairs for a small PA company in Birmingham, UK. Whilst working in a hire warehouse in Bristol he developed an interest in rigging and managed to pick up some good experience. A few years later he started working as a freelance rigger. He had a hiatus from the entertainment industry for about five years where he was first a greenkeeper and then helped run a pub in Devon. In 2010, Tom started an Open University engineering degree which he graduated with honours in 2016. During that time, he started work at Mantracourt Electronics, a leading electronics company specializing in signal conditioners. Mantracourt Electronics also manufacture the Broadweigh range of load monitoring shackles. Learn more at https://www.broadweigh.com/.

Tom Lilly, Applications Engineer at Broadweigh