INTERNATIONAL cranes AND SPECIALIZED TRANSPORT

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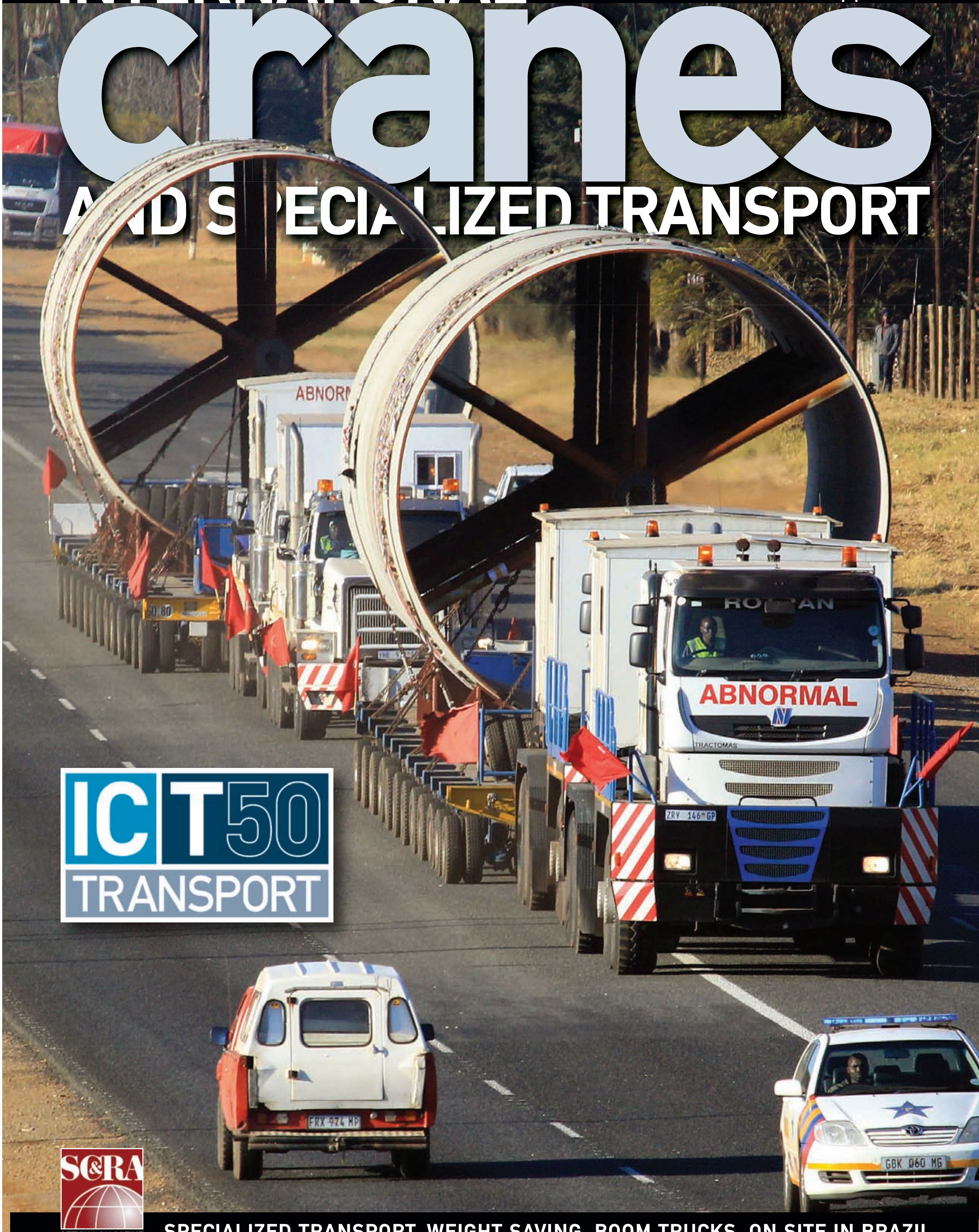

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SPECIALIZED TRANSPORT, WEIGHT SAVING, BOOM TRUCKS, ON SITE IN BRAZIL

Mechanical advantage

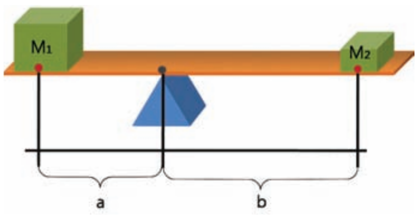
In a slight variation from the usual theme of our technical how-to series, this month MARCO VAN DAAL uses a case study to illustrate several of the principles and calculation methods explained in earlier articles

In our heavy lift and heavy transport industry we often rely on machines or tools that make our life easier. Such machines make use of a phenomenon called mechanical advantage. Mechanical advantage is a measure of the force amplification achieved by the tools in question. Many of the machines that we use are complex (and expensive). The principles behind such machines, however, are often very basic.

Hydraulic gantries, climbing jacks, platform transporters and hydraulic cranes are all examples of complex machines but they all rely on the principle of pressure (hydraulic oil from a pump) applied against an area (the piston in a cylinder or ram) creating a force amplification that can lift or move an object (see *IC* November 2013, page 37).

This article highlights two types of mechanical advantage used by a crane. Let's start with a definition of a crane:

FIGURE 1



ABOUT THE AUTHOR

Marco van Daal has been in the heavy lift and transport industry since 1993. He started at Mammoet Transport from the Netherlands and later with Fagioli PSC from Italy, both leading companies in the industry. His 20-year plus experience extends to five continents and more than 55 countries. It resulted in a book *The Art of Heavy Transport*, available at: www.khl-infostore.com/books Van Daal has a real passion for sharing knowledge and experience and holds seminars around the world.

"A crane is a machine that is used to lift or lower a weight. By use of mechanical advantage it can handle weights beyond the normal capability of man."

This definition is actually twofold, the first part explains the purpose of a crane and the second part explains the reason for the mechanical advantage.

The lever

The first type of mechanical advantage that a crane uses is its boom. The boom makes use of the principle of the lever. A lever is a device consisting of a beam connected to the ground by a hinge or pivot, called the fulcrum. See Figure 1.

The mechanical advantage of a lever can be determined by reviewing the moments about the fulcrum.

$M_1 * a = M_2 * b$

Where M_1 and M_2 are the weights, and a and b are the distances to the fulcrum.

When the input force $M_2 = 50$ (kg or LBS or ton) and a = 10 and b = 20 (centimetre or metre or foot), the formula $M_1 * a = M_2 * b$ leads to $M_1 = 100$.

The mechanical advantage of the lever is the ratio of the output force (M_1) to the input force (M_2) in this case is $M_1 / M_2 = b / a = 2$.

Crane application

Review Figure 2 and assume that M_1 (the counterweight) is 1,000 ton at a distance of 40 ft (distance a) from the centre of rotation. The crane boom is set at 16 ft (distance b). What is the maximum weight (M_2) the crane can lift (before safety factors are applied to the lift chart).

$M_1 * a = M_2 * b$
$1{,}000 * 40 = M_2 * 16$
$M_2 = 2{,}500$ ton

The mechanical advantage is output / input = $M_2 / M_1 = 2{,}500 / 1{,}000 = 2.5$

This type of tool, the lever, can result in a mechanical advantage of greater than 1 but also of smaller than 1. This may seem strange to have a tool that offers a mechanical advantage smaller than 1 but, if the tool still handles weights beyond the capability of man, it does make sense.

Let us assume that the crane in Figure 2 booms down from 16 to 50 ft (distance b). What would be the maximum weight the crane can lift in this scenario?

$M_1 * a = M_2 * b$
$1{,}000 * 40 = M_2 * 50$
$M_2 = 800$ ton

The mechanical advantage is output / input = $M_2 / M_1 = 800 / 1{,}000 = 0.8$

Energy conservation

This law states that the total energy of an "isolated or closed system" (a system from which no energy is withdrawn nor energy is added to it) remains constant; it is said to be conserved over time. As energy can be neither created nor be destroyed it will stay within the "isolated system".

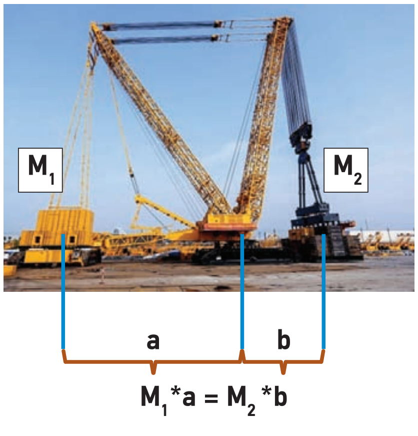
This means that the mechanical advantage of 2 in Figure 1, where the lever lifts more weight ($M_1 = 100$) that what is applied to it ($M_2 = 50$) has to be at the cost of another property to "balance" the "isolated system".

Figure 1 shows the lever in balance but if the weight M_2 would move downwards with a speeds of $V_2 = 1$ (ft/sec or mtr/sec) than M_1 would move upwards with a speed equal to $V_1 = V_2 / M.A. = 1 / 2 = 0.5$ (ft/sec or mtr/sec). M.A. being the mechanical advantage.

The increased weight on the side of M_2 (by a factor equal to the mechanical advantage) and the decrease in speed on that same side by an equal factor complies with the law of conservation of energy.

For those who are interested, the two types of energy described here are the potential energy (P.E.) and the kinetic

FIGURE 2



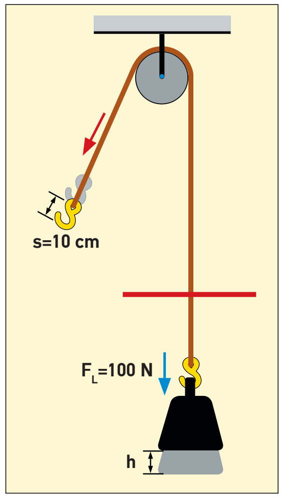


FIGURE 3

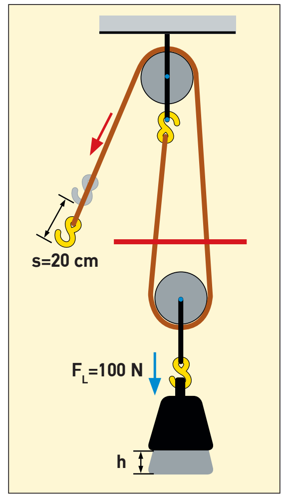


FIGURE 4

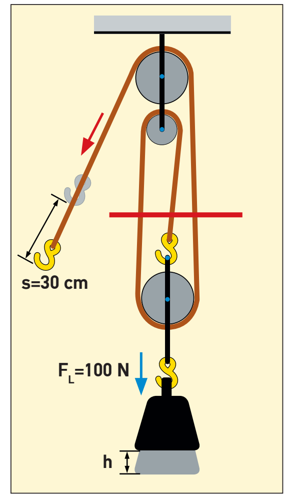


FIGURE 5

energy (K.E.). The sum of both is called the mechanical energy (M.E.) and is constant for a closed system as mentioned.

The pulley

The second type of mechanical advantage a crane uses is the hoist. The hoist makes use of the "principle of the pulley". A pulley is a wheel on an axle or shaft that is designed to support movement and change of direction of a cable along its circumference. Pulleys are used in a variety of ways to lift loads, apply forces, and to transmit power.

On a crane the hoist consists of multiple pulleys that enjoy a mechanical advantage to lift loads with low effort (compared to the load lifted). Figure 3.

This figure shows a load F_L = 100 Newton (roughly 10 kg or 20 LBS) being lifted using a single pulley. To determine the mechanical advantage, draw a line (shown in red) just above the load to be lifted and count the parts of line that are "cut". In this case the red line cuts 1 part of line.

The line pull (L.P.) defined as the amount of force required at the end of the rope to lift the load can be calculated as L.P. = F_L / # of parts = 100 / 1 = 100 Newton.

Surely this outcome is no surprise.

The mechanical advantage is output / input = F_L / L.P. = 100 / 100 = 1

The pulley arrangement in Figure 3 offers no mechanical advantage. The only change the pulley makes is that a "downward force" (the line pull) creates an "upward lift" (the load rises), this "change of direction" is one of the uses of a pulley.

Figure 4 shows a hoist with two pulleys lifting the same weight F_L. The red line cuts 2 parts of line, the line pull is therefore: L.P. = F_L / # of parts = 100 / 2 = 50 Newton.

The mechanical advantage is:
output / input = F_L / L.P. = 100 / 50 = 2
On this case only 50 Newton are required to lift a 100 Newton load. Figure 5 shows a hoist with two pulleys lifting the same weight F_L. The red line cuts 3 parts of line, the line pull is therefore L.P. = F_L / # of parts = 100 / 3 = 33.3 Newton.

The mechanical advantage is:
output / input = F_L / L.P. = 100 / 33.3 = 3

On this case only 33.3 Newton are required to lift a 100 Newton load.

Energy law

As with the lever, the mechanical advantage of Figures 4 and 5 has to be at the cost of another property to balance the closed system as no energy is added or subtracted from it.

In Figure 4 the line pull (L.P.) causes a movement in the rope (at the yellow hook) of S = 20 cm. This 20 cm causes the load F_L to be raised by h = 10 cm due to the mechanical advantage of the pulley arrangement. To comply with the law of conservation of energy, the mechanical advantage in line pull of F_L / L.P. = 2 means a mechanical advantage in distance of h / s = 10 / 20 = 0.5. (output / input). In popular terms this means that with this pulley arrangement you can lift twice the amount of weight but you need twice the amount of rope to do so.

Similarly in Figure 5, the line pull (L.P.) causes a movement in the rope (at the yellow hook) of # = 30 cm. This 30 cm causes the load F_L to be raised by h = 10 cm. Again, due to the law of conservation of energy, the mechanical advantage in line pull F_L / L.P. = 3 means a mechanical advantage in distance of h / s = 10 / 30 = 0.3 (output / input).

Following the same logic, Figure 3, where the mechanical advantage was 1 due to line pull, should have a mechanical advantage of 1 in distance as well. This means that a movement of S = 10 cm at the yellow hook causes the loaf F_L to rise by 10 cm. ■