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[54] CRANE LOAD INDICATING ARRANGEMENT

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[51] **Int. Cl.**[2] **G01G 19/04;** G01G 23/18; G01G 19/14
[58] **Field of Search** 177/45, 145, 147, 151, 177/1, 25, 136; 214/2

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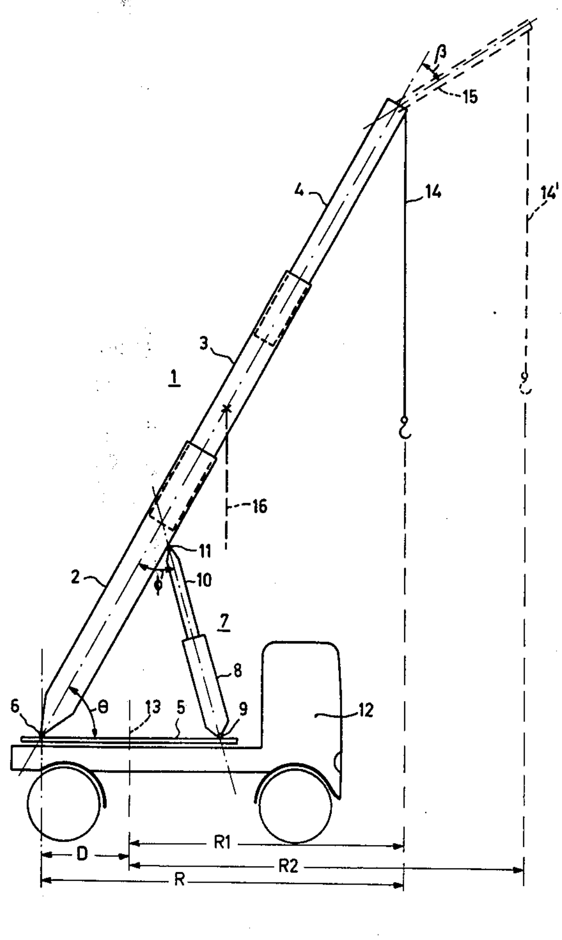
Attorney, Agent, or Firm—Frank R. Trifari; Bernard Franzblau

[57] **ABSTRACT**

A crane load indicating arrangement for a crane having a luffing boom and which provides a load indication in terms of total effective load, the load indication being with respect to both radius related duties and angle related duties. The arrangement provides a load indication with and without a fly jib attached to the end of the boom and also includes means for compensating for boom deflection.

18 Claims, 5 Drawing Figures



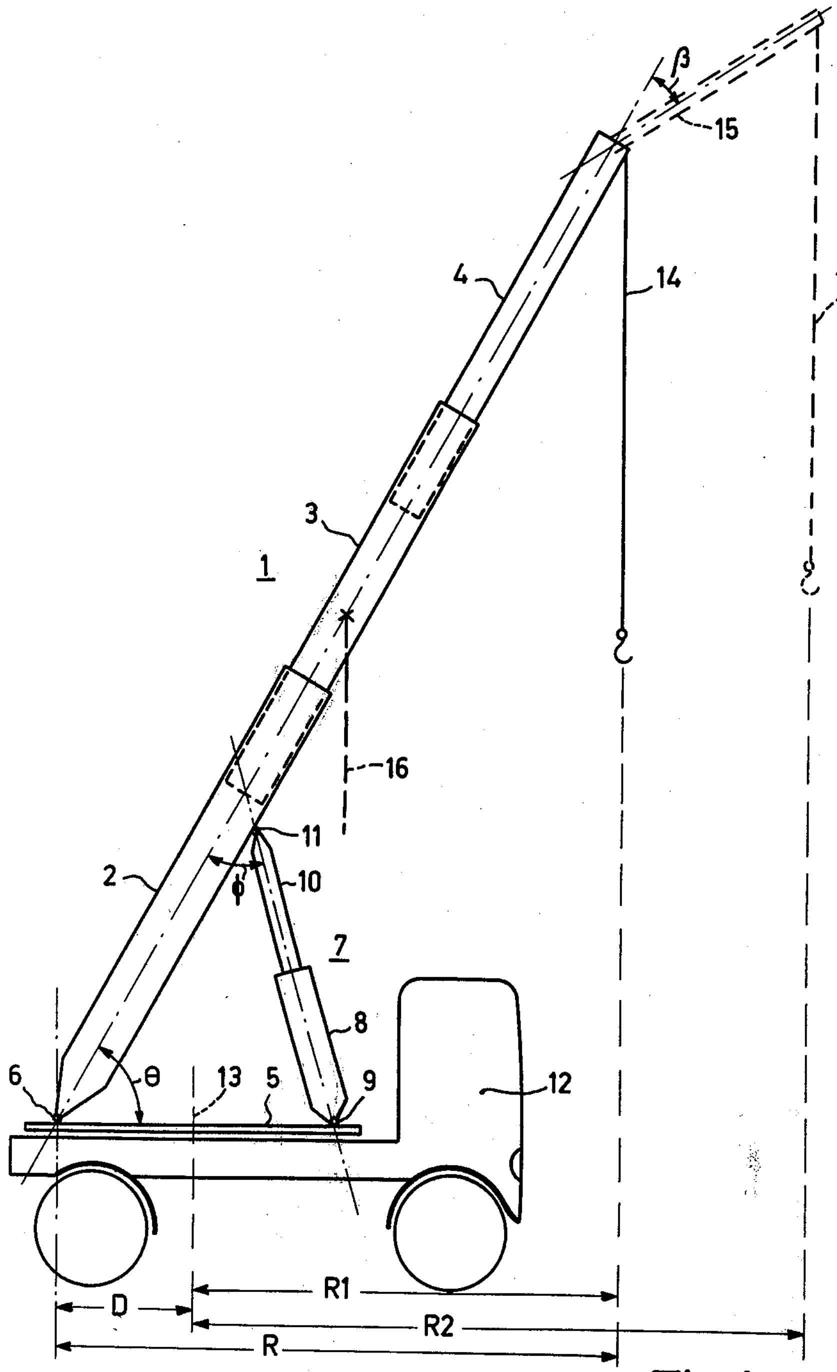


Fig.1

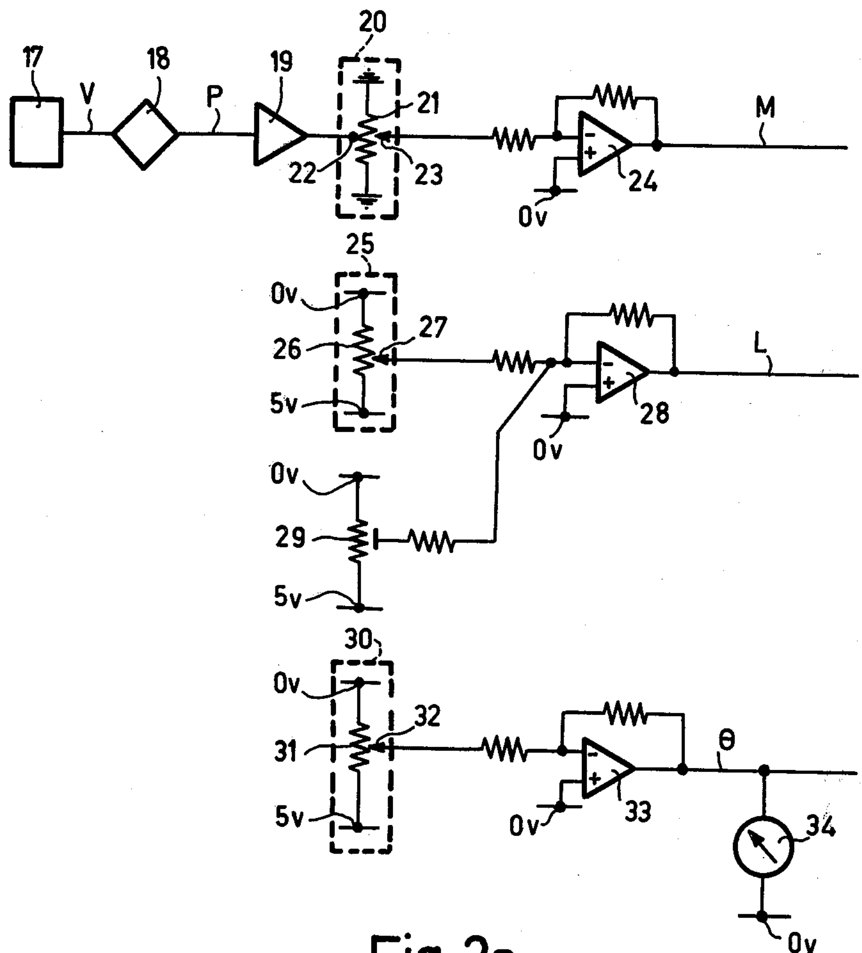

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Fig. 2a

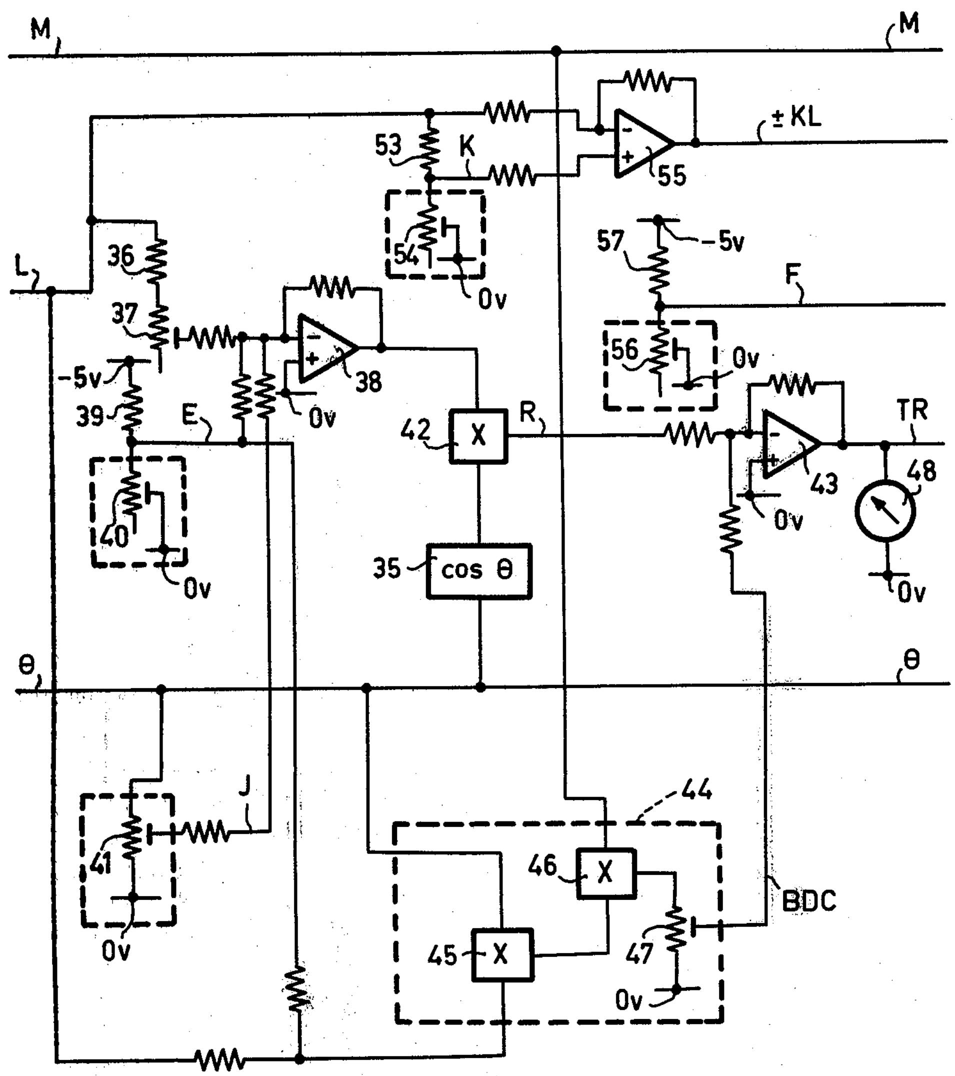
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Fig.2b

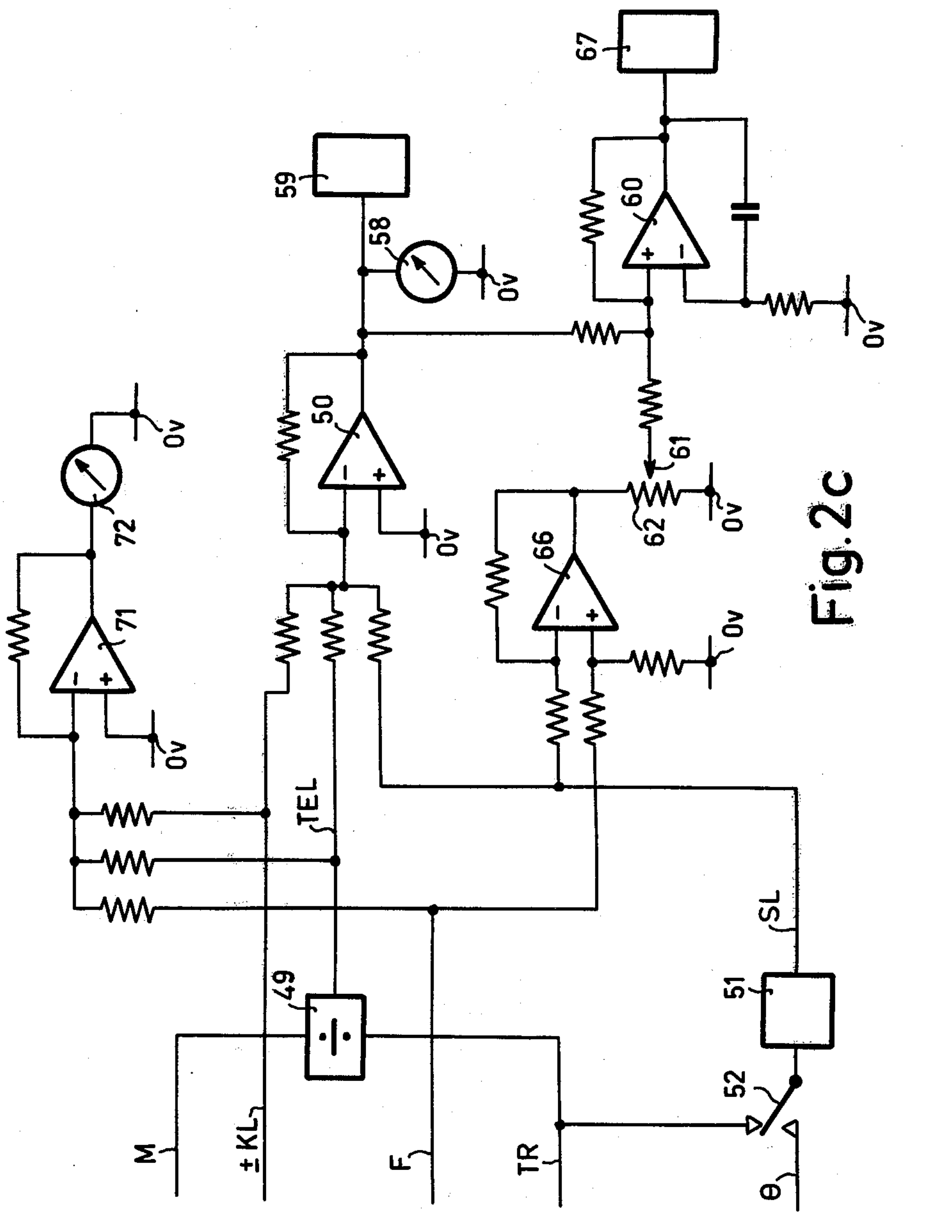
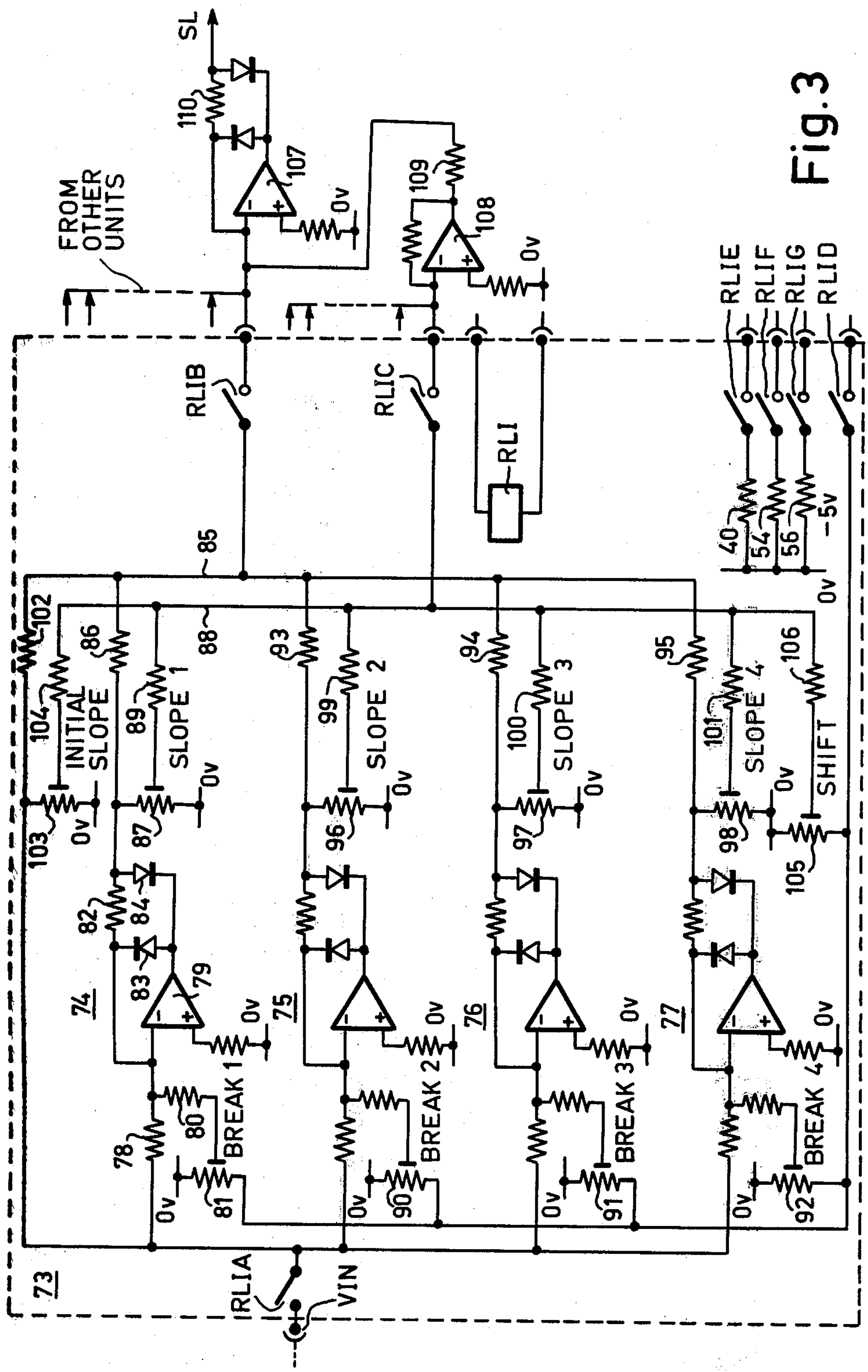


Fig. 2c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SLOPE 4
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78
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BREAK 1
BREAK 2
BREAK 3
BREAK 4
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92
40
54
56
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73
RLIA
VIN

Fig.3

CRANE LOAD INDICATING ARRANGEMENT

This invention relates to a load indicating arrangement for use with cranes, derricks and other lifting apparatus of the type having a pivoted boom which can be luffed by a hydraulic ram or other boom supporting means. It has a particular but non-exclusive application to mobile cranes of the above type having an extensible boom which can be slewed through the whole or part of a circle.

A typical mobile crane of the above type has a boom comprising a plurality of telescoping sections, of which the lowermost is pivoted to a base unit for luffing movement by means of a hydraulic ram. One end of the ram is also pivoted to the base unit, and the other end is pivoted to a point on the lowermost section so as to support the boom at an angle (the luff angle) to the horizontal which is determined by the extension of the ram. The base unit is mounted on a road or rail chassis and is arranged to slew through the whole or part of a circle about a vertical axis. As an alternative to the hydraulic ram, the boom can be supported by a winch cable which is secured to its outer end and which can be wound in and out to luff the boom. For this alternative the boom is not usually telescopic.

The chassis may be provided with outriggers or blocking girders, which are carried in a stowed position when the crane is in road trim, but which can be extended outwards from the chassis and have their outer ends blocked up from the ground in order to increase the crane's stability and to relieve the load on the road wheels.

For basic duties of the crane, a load is supported by a hoist rope or cable passing over a sheave at the outer end of the boom. The crane can lift loads located within a range of radii measured from its slewing centre. For lifting light loads, a fly jib may be secured to the outer end of the boom. This increases the radius of action of the crane.

Such a crane has a number of possible modes of operation, for example, blocked, free-on-wheels, and with or without fly jib. In whatever mode the crane is operated, the load must be limited so that the overturning moment which it produces does not imperil the stability and also that no component part of the crane is overstressed.

When operating without a fly jib, the prime consideration is stability. Stability is greatest when the outriggers are extended and blocked up. In the free-on-wheels condition, stability is frequently greater when the boom is extended over an end of the chassis than when it is slewed to one side or the other, because the wheel base length of the chassis is usually substantially greater than its track width.

A fly jib is usually of much lighter construction than the main boom to which it is secured, and is adapted to support only relatively light loads. Over much of the radius of operation of the crane, the strength of the fly jib is the limiting factor in determining the maximum safe load, and the question of stability does not arise. At large radii, however, when the main boom is fully extended and at a small luff angle, the moment produced by a load which is within the strength capability of the fly jib may reach the stability limit.

The crane manufacturer prepares rating tables which give the maximum permissible hook loads which the crane may lift. A separate table is prepared for each possible mode of operation. In general, for modes of operation involving basic duties, the safe hook load is related to radius from the slewing centre (i.e. radius-related duties). For duties involving the fly jib, the safe hook load may be related to luff angle below a given value of radius (i.e. angle-related duties) and to radii above that value, or be related to luff angle for all radii.

In our co-pending U.S. patent application Ser. No. 468,764, there is described such a load indicating arrangement in which for radius-related duties a loading indication is produced in terms of turning moment of the hook load about the boom pivot point, whereas for angle-related duties a loading indication is produced in terms of actual hook load.

In contrast, the present invention provides a load indicating arrangement including means for producing a loading indication in terms of total effective load. Such an indication can be in respect of both radius-related duties and angle-related duties.

More specifically, there is provided according to the present invention a load indicating arrangement for use with a crane or other lifting apparatus of the type specified, which arrangement can comprise, means for producing a first output representative of the total turning moment of the boom about its pivot in supporting a load, means for producing a second output representative of the horizontal distance between the boom pivot point and the load, means for producing a third output as the quotient obtained by dividing said first output by said second output, said third output being thus representative of total effective load, a law generator unit in respect of each mode of operation of the crane, each unit being adapted to produce a fourth output representative of the maximum safe loading for the crane in the appertaining mode of operation for the load radius or luff angle, as the case may be, currently obtaining, and means for comparing said fourth output with said third output to provide an indication of the actual crane loading relative to the maximum safe loading.

In the above context, the term "weight of the boom alone" is meant to embrace the weight of the boom with or without a fly jib, together with the weight of the sheave, hoist rope, hook, etc., that is, the total weight of the structure that supports the load, but excluding the weight of the load. The term "total effective load" means the weight, at the hook, of the actual load, plus the total weight of the structure acting through its centre of gravity; that is, in the latter respect, an equivalent weight at the hook which produces the same turning moment as the weight of the structure acting through its centre of gravity.

In carrying out the invention said first output is preferably determined in terms of the angle included between the boom supporting means and the boom, and of the reaction sustained by the boom supporting means in supporting the boom and any load suspended from it. More specifically, transducer means can be provided for producing an output which is a function of said reaction, together with angle sensing means for modifying said output in accordance with the sine of the angle included between the boom supporting means and the boom to produce said first output.

The word "reaction" is used herein to signify the force to which the boom supporting means is subjected in supporting the boom (and load). If the boom supporting means is a hydraulic ram, then the force would be a function of the fluid pressure in the ram, whereas if the boom supporting means is a winch cable, then the force would be a function of the stress to which the cable is subjected. The reaction sustained by the boom supporting means can thus readily be determined as an electrical signal by means of a pressure transducer or a resistance strain gauge transducer which is appropriately mounted to suit the crane design.

In order that said third output represents accurately the total effective load, the arrangement preferably includes means for producing a fifth output which is representative of the change in the position of the centre of gravity of the boom structure for change in boom length, together with means for combining said fifth output with said third output to produce a corrected third output. The arrangement also preferably includes means for correcting for boom deflection (or bending) in the production of said second output, to take into account the effective increase in the horizontal distance of the load from the boom pivot point due to boom deflection; that is, the effective increase in load radius.

For modes of operation involving basic duties, each law generator unit concerned is responsive to the second (radius) output (corrected for boom deflection) which is representative of the horizontal distance between the boom pivot point and the load (i.e. radius-related operation), whereas for modes of operation involving fly jib duties, each law generator unit concerned is responsive to an output from a boom angle sensing means (i.e. luff angle-related operation).

Each law generator unit may be brought into use selectively by means of mode sensors which are adapted to be activated selectively as the crane is set up for different modes of operation. Alternatively, plug-in law generator units can be provided for each mode of operation.

Means may also be provided to produce an output which is representative of actual hookload and hook load be utilised to operate a meter which is calibrated to show actual weight of load. Other meters can be provided which are responsive to said radius output and the output from the boom angle sensing means respectively, to show load radius and luff angle, respectively.

In order that the invention and the manner in which it is to be performed may be more fully understood, an embodiment thereof will now be described, by way of example, with reference to the accompanying drawings, of which:

FIG. 1 is a diagrammatic representation of a mobile crane,

FIG. 2 (which comprises FIGS. 2*a*, 2*b* and 2*c* laid side-by-side in that order) is a block schematic diagram of load indicating arrangement according to the invention; and

FIG. 3 is a schematic diagram of a law generator unit for use in the arrangement of FIG. 2.

Referring first to FIG. 1, the mobile crane there shown has a boom indicated generally by the reference numeral 1. The boom comprises a lower section 2, an intermediate section 3 slidable telescopically within the upper end of the section 2, and an upper section 4 slidable telescopically within the upper end of the section 3. Extension means such as a hydraulic ram (not shown in FIG. 1) is provided to position the section 3 with respect to the section 2 and to position the section 4 with respect to the section 3 so that the overall length of the boom 1 may be adjusted to any desired value between a maximum and a minimum limit.

The lower end of the boom section 2 is pivoted to a horizontal base unit 5 at a point 6 so as to permit luffing movement of the boom 1. A hydraulic luffing ram 7 has one end of its cylinder 8 pivoted to the base unit 5 at a point 9 and its piston rod 10, which extends through the other end of the cylinder 8, pivoted to the boom section 2 at a point 11. The axis of the boom 1 makes an angle θ (the luff angle) with the horizontal, θ being variable by varying the extension of the luffing ram 7.

The base unit 5 is mounted upon a road vehicle chassis 12 and is arranged for rotation with respect to the chassis about a vertical axis on a slewing centre 13.

For basic duties of the crane,, a load is suspended by a hoist rope 14 which passes over a sheave (not shown) at the outer end of the boom section 4 to a winding drum (also not shown). It will be seen that by varying the extension of the boom and/or the luff angle the horizontal distance R1 between the slewing centre 13 and the hoist rope 14 can be varied so as to permit lifting of loads located within a range of radii from the slewing centre.

For fly duties of the crane, a fly jib 15, shown in broken outline in FIG. 1, is secured to the outer end of the boom section 4, and the hoist rope 14′ passes over a sheave (not shown) at its outer end. For any combination of boom extension and luff angle, the horizontal distance R2 between the slewing centre 13 and the hoist rope 14′ is greater than the corresponding value of R1.

A load suspended by the hoist rope 14 (14′) exerts a turning moment about the boom pivot point 6. To this is added the turning moment exerted by the weight of the boom acting through its centre of gravity 16. The total turning moment is opposed by the component normal to the boom axis of the reaction of the luffing ram 7.

A load indicating arrangement for a mobile crane of the above type will now be described with reference to FIGS. 2 and 3. The arrangement will be described firstly in relation to basic duties of the crane and additional features required in respect of fly duties will follow.

Referring to FIG. 2, a reference signal generator 17, for example a 700 Hz square wave oscillator, provides a stable signal V of constant voltage. This signal V is supplied to a transducer 18 which is connected to the luffing ram 7 (FIG. 1) and is adpated to produce an output P which is a function of the reaction sustained by this ram in supporting the boom 1 and any load suspended from it. When the ram 7 is of the single-acting type, the output of the transducer 18 is a function of (e.g. proportional to) hydraulic fluid pressure below the ram piston 10. For a double-acting ram the transducer output is a function of (e.g. proportional to) the difference between the pressures below and above the ram piston 10, modified by the ratio of the effective areas of the lower and upper sides of the piston. For a double-acting ram, two transducers are usually fitted to measure pressures above and below the ram piston, and their outputs are combined electrically to produce a resultant transducer output.

The signal P is applied via an amplifier 19 to an input terminal of a ram angle sensor 20, comprising a potentiometer having a resistive track 21. The ends of the track 21 are connected to ground and the signal P is applied at a tapping point 22 intermediate the ends of the track 21. The potentiometer body is mounted in fixed relation to the boom 1 and a slider 23, which contacts the track 21, is mechanically coupled to the luffing ram 7 so that it moves over the track 21 when the angle ϕ included between the boom 1 and the ram 7 changes with changing extension of the ram. The track 21 is graded so that the signal appearing at the slider 23 is proportional to sin ϕ. The slider 23 is connected to an input terminal of an amplifier 24 which provides an amplified output M proportional to P sin ϕ, i.e. to the component of the ram reaction normal to the boom 1. Output M is therefore also proportional to the total turning moment of the boom about the boom pivot point 6.

A boom extension sensor 25 comprises a potentiometer having a resistive track 26 and a slider 27 which is mechanically coupled to the boom so as to be driven over the track 26 as the boom extension is varied from minimum to maximum. The end of the track 26 corresponding to maximum extension is connected to the negative terminal of a stabilised reference supply (e.g. –5v), the other end being connected to the Ov side of the supply. It is assumed for the purposes of the present description that the load indicating arrangement is energised by a –5V stabilised reference supply, but it is to be understood that this voltage is given only as an example and that the actual voltage supply required depends upon the type of circuit elements used in the load indicating arrangement. The slider 27 is connected to an input terminal of an amplifier 28. There is also connected to this input terminal of amplifier 28 a present potentiometer 29 connected across the –5V reference supply. This potentiometer 29 is provided to facilitate initial setting-up of the arrangement. The amplifier 28 gives an output L proportional to the boom extension.

A boom angle sensor 30 comprises a potentiometer mounted for movement with the boom 1 and having a resistive track 31 connected across the –5v reference supply. A slider 32 is gravity actuated, e.g. by a pendulum, so that it moves over the track 31 as the luff angle changes when the extension of the luffing ram 7 is varied. The slider 32 is connected to an input terminal of an amplifier 33 which gives an output θ proportional to the luff angle θ. This output may be used to drive a meter 34, which is scaled in terms of luff angle, and this output is also applied to a cosine law generator unit 35. This unit 35 is preferably of a type in which the slope of its input/output characteristic is modified stepwise in accordance with changes in its input amplitude so as to produce an overall characteristic comprising a plurality of linear sections of differing slopes and approximately closely to a cosine law. The resultant output from unit 35 is thus proportional to the cosine of the luff angle θ.

The boom extension output L produced by the amplifier 28 is fed via a gain control element comprising a fixed resistor 36 and a preset variable resistor 37 to an input terminal of a summing amplifier 38. Also fed to this input terminal is an output E which is a function of the length of the boom when fully retracted and which is obtained from a potential divider comprising a fixed resistor 39 and a preset variable resistor 40 connected in series across the –5v reference supply.

The fully-retracted length of the boom is constant for any one mode of operation of the crane, but may vary from mode to mode. As will be described more fully later, a plurality of resistors such as resistor 40 is provided, each one preset to the value appropriate to a particular mode, and means represented by the dotted rectangle including resistor 40 are provided for selecting the particular resistor corresponding to each mode of operation.

For radius-related duties, the output E is made proportional to the fully-retracted length of the boom in each mode.

The resultant output of the amplifier 38 is thus substantially proportional to the total length of the boom structure from which the load is suspended and is applied as a first input to an analogue multiplying unit 42. The output of the cosine law generator unit 35 is applied as a second input to the unit 42. Thus, the unit 42 produces a resultant output R proportional to $(L + E)$ cos θ. It can be seen from FIG. 1 that $(L + E)$ cos θ is the basic horizontal distance R between the boom pivot point 6 and the load, and that it equals the sum of the radius R1 of the load from the slewing centre 13 and the distance D between the slewing centre and the boom pivot point.

The output R is applied to an input terminal of a summing amplifier 43. There is also applied to this input terminal an output BDC from a circuit element 44 which is provided to correct for boom deflection (or bending). Any deflection of the boom will result in an increase of the load radius, so that the output R is not truly representative of the true load radius. The circuit element 44 comprises two analogue multiplying units 45 and 46. The outputs L and E are summed to form one input to the unit 45 and the output θ is applied to the unit 45 as a second input. The resultant output $(L + E)\ \theta$ from unit 45 is thus proportional to the product of the total length of the boom and the luff angle θ. This resultant output is applied as one input to the unit 46 and the output M, proportional to the total turning moment of the boom, is applied as a second input to this unit 46. A potentiometer 47 is connected between the OV line and the output terminal of the unit 46. This potentiometer is preset on initial setting-up of the arrangement to provide a resistance value appropriate to the particular boom structure concerned. The output from the unit 46 is the product of the output M and the output $(L + E)\ \theta$ and is adjusted in magnitude by the setting of the potentiometer 47 to form the output BDC which is a function of the boom deflection that occurs for the boom length, luff angle and total turning moment currently obtaining. As aforesaid, boom deflection results in an increase in the radius that the load is at so that the output BDC is summed with the output R at amplifier 43, which latter produces a true radius output TR. A meter 48 is provided to indicate true radius of the load in response to the true radius output TR.

The output TR is applied as one input to an analogue dividing unit 49, and the output M is applied to this unit 49 as a second input. The unit 49 is responsive to these two inputs to produce an output TEL which is representative of total effective load; that is, total turning moment divided by true radius equals total effective load at hook. This output TEL is applied to an input terminal of a summing amplifier 50. A further output SL is produced by a mode unit 51, which will be described presently, and this output SL is also applied to the input terminal of the amplifier 50. For the radius-related duties being described, the unit 51 is responsive to the output TR to produce the output SL. This output SL is proportional to the maximum safe total effective load which the crane is permitted to withstand for the boom length and luff angle that currently obtain (i.e. the load radius) in any particular mode of operation. The output SL is arranged to have a polarity opposite to that of the output TEL.

However, for a telescopic boom structure, it is not sufficient merely to combine algebraically the outputs SL and TEL to provide a net input to the amplifier **50** that can be utilised to give an indication of the crane loading, because for radius-related duties, a particular load radius can be attained with a variety of boom extensions and luff angles. An equivalent weight at the hook which produces the same turning moment as the weight of the boom structure acting through its centre of gravity is determined by the actual weight of the boom structure and by the position of the centre of gravity. The latter will change as the boom extension is varied and the change will be affected by the telescopic structure of the boom. It can be shown that an expression for such an equivalent weight has the form $(F \pm KL)$, where F is a constant related to the weight of the boom structure, and KL is related to the position of the centre of gravity of the boom structure, for a given mode of operation, K being a constant for a particular boom and L being the boom extension.

In order to provide the output K, the arrangement further comprises a potential divider comprising a fixed resistor **53** and a preset variable resistor **54** which are connected in series between the output terminal of the amplifier **28** and the OV line. The value of the resistor **54** is set to produce an output proportional to K at the tapping point of the potential divider. Since the value of K may vary from mode to mode of operation of the crane, a plurality of resistors such as resistor **54**, each one preset to the value appropriate to a particular mode, is provided together with means (to be described hereinafter) represented by the dotted rectangle including resistor **54** for selecting the particular resistor corresponding to each mode of operation. The outputs L and K are applied to respective input terminals of an amplifier **55** which produces the output $\pm KL$.

In order to provide the output F, there is provided a further potential divider comprising a preset variable resistor **56** and a fixed resistor **57** connected in series across the −5v reference supply, the value of the resistor **56** being set so as to produce an output proportional to the constant F at the tapping point of the potential divider. In this instance also a plurality of preset resistors such as resistor **56** is provided for each mode of operation, together with means represented by the dotted rectangle including the resistor **56** for selecting the particular resistor corresponding to each mode.

The output KL is applied as a further input to the amplifier **50**. When therefore, the crane has reached its maximum safe total effective load in a particular mode of operation, $SL = TEL \pm KL$ and the net input to the amplifier **50** is zero. The output of amplifier **50** is consequently also zero and is indicated at the calibration point of a safe working load meter **58** connected to the output terminal of the amplifier **50**, the meter zero having been offset mechanically to this calibration point. Increase of total effective load above the rated maximum ($TEL \pm KL > SL$) will provide a net input of one polarity and a corresponding output from the amplifier **50** which will drive the meter **58** into an overload region of its scale. Total effective loads less than the rated maximum ($SL > TEL \pm KL$) will produce a net input and corresponding output from the amplifier **50** of the opposite polarity, driving the meter **58** into a safe region of its scale and so indicating available lifting capacity. The output of the amplifier **50** may also be applied to an alarm unit **59** which is adapted to produce an audible and/or visual alarm signal when the maximum safe total effective load is reached or exceeded.

The arrangement may also include means to provide a preliminary warning signal when the total effective load exceeds a predetermined percentage of the maximum safe total effective load, and/or trip circuits to cut off power to the hoist motor in the event of an overload. However, it may be preferred that a preliminary warning signal is provided when a predetermined percentage of the maximum safe weight of actual hook load, as distinct from total effective load, is exceeded. To provide this latter facility, the arrangement includes a further amplifier **60** to the input terminal of which the output of amplifier **50** is applied. The output SL is applied to one input terminal of an amplifier **66** and the output F is applied to a second input terminal of the amplifier **66.** It is arranged that these outputs SL and F are of opposite polarity so that the output of amplifier **66** is $(SL + F)$. This latter output is applied across a potentiometer **62** the slider **61** of which is connected to the input terminal of amplifier **60.** For the condition $SL > TEL \pm KL$, the output of amplifier **50** is of opposite polarity to the output from amplifier **66.** Thus, the net input to amplifier **60** becomes zero to cause an alarm unit **67** at the output of amplifier **60** to operate when the output of amplifier **50,** which corresponds to available lifting capacity, reduces to a value corresponding to a percentage of the output $(SL + F)$, as determined by the setting of the potentiometer **61.** It is to be noted that the percentage of the output $(SL + F)$ never reduces to zero, even though the output SL may do so, because of the contribution of the output F. Thus, if a crane controlled by the arrangement is operating at extreme values of radius or luff angle, the alarm unit **67** may operate to indicate very little lifting capacity is available even before any load is put on the hook.

The outputs TEL, ± KL and F may also be combined at the input terminal of a further amplifier **71** to provide a net input thereto that is proportional to the weight of the hook load. The output of amplifier **71** drives a meter **72** which is calibrated to indicate actual hook load.

For angle-rated duties (i.e. usually using a fly jib) the unit **51** is responsive to the output θ to produce the output SL, relay changeover contacts **52** being provided to select which of the outputs TR and θ is applied to the unit **51.** Thus, for angle-related duties, the output SL is proportional to the maximum safe total effective load which the crane is permitted to withstand for the luff angle that currently obtains. The load radius is not taken into consideration because the maximum safe loading is limited by the strength of the fly jib. The outputs SL, ± KL and F are utilised in the same manner as for radius-related duties to drive the meters **58** and **72** and to operate the alarm units **59** and **67.**

Unlike radius-related duties, for which the output E is made proportional to the fully-retracted length of the boom in each mode, for angle-related duties using an offset fly jib, the output E is made different from such directly proportional value to take into account the fact that, for any given luff angle and load, the ratio of the turning moments due to the load alone (i.e. ignoring the turning moment of the boom structure) for a fully-extended boom and a fully-retracted boom is not equal to the ratio of the corresponding load radii. This inequality may be appreciated by considering the effect of telescoping the boom between fully-extended and fully-retracted positions at different luff-angles, from which it can be seen that the proportion of load radius due to the offset fly jib is greater at large luff angles than at small luff angles. A similar consideration applies to the effect of the weight of the fly jib acting through its centre of gravity.

Looked at another way, because of the offset of the fly jib, the turning moment due to the hook load is not normal to the boom axis, but is normal to a line joining the pivot point **6** (FIG. **1**) to the end of the fly jib. Similarly, the turning moment due to the weight of the fly jib acting through its centre of gravity is not normal to the boom axis. Therefore, the output M, which is derived from the actual total turning moment that is considered as being normal to the boom axis, does not accurately represent the total turning moment when an offset fly jib is mounted on the boom. The error in the output M varies with boom extension and with luff angle.

Therefore, in order to obtain an accurate value for the output TEL when an offset fly jib is fitted, the output M is divided, not by a true radius output which is directly proportional to the load radius (i.e. the output TR as in radius-related duties), but by a radius output which varies from the true radius output on the same manner as the output M varies from the true total turning moment. This is achieved to a sufficient degree of accuracy by adding an increment related to the length of the fly jib to the output E, this increment being provided by adjustment of the potentiometer **40.** However, this would give the appropriate radius correction only for one luff angle. In order to provide the appropriate radius correction at any luff angle, the arrangement further comprises a potentiometer **41** which is connected at one end to receive the output θ and to the OV line at the other end. This potentiometer **41** is preset to produce a corrective output $J = \theta/K$, where k is a constant for any one mode of angle-related operation. This output J is applied to the input terminal of the amplifier **38,** together with the output E and the output L. Thus, the output R from the unit **42** is now $(L + E + J)$ cos θ. As a consequence, the output TR is no longer a true radius output, but is corrected to give a sufficiently accurate value for the total effective load output TEL. Because the output TR is no longer a true radius output, the load radius indicating meter **48** is not used for offset fly jib operation. However, this is not a serious loss because the load radius is not significant for angle-related duties.

The mode unit **51,** which will now be described with reference to FIG. **3,** comprises a plurality of similar law generator units, each adapted to provide an output which varies according to a predetermined law. One law generator unit is provided for each separate mode of operation which the crane can perform, and is preset to a law corresponding to the manufacturer's rating curve for that mode of operation. Means are provided to select the one law generator unit corresponding to the mode of operation being performed.

Referring to FIG. **3,** a law generator unit **73** is carried on a printed circuit board indicated by the broken line rectangle. The circuit of this unit comprises a plurality of similar threshold amplifiers indicated generally by the references **74, 75, 76** and **77.** A positive input V_{IN}, which can be either the luff angle output θ from amplifier **33** or the true radius output TR from amplifier **43** (see FIG. **2**), is applied to each threshold amplifier. Considering first the threshold amplifier **74,** the input V_{IN}, which passes through a contact RLIA of a relay RL1 which is energised when the particular unit **73** is in use, is fed via an input resistor **78** to an input terminal of an amplifier **79.** A negative bias signal is fed to the same input terminal via a resistor **80** from the slider of a preset potentiometer **81** (Break **1**) connected between a −5v reference supply (via relay contact RLID) and ground. The output terminal of amplifier **79** is connected to the same input terminal thereof via a feedback circuit comprising a resistor **82** and two diodes **83** and **84.** The arrangement is such that if the magnitude of the positive input V_{IN} is less than the magnitude of the negative bias signal, giving a net negative input to the amplifier **79,** the amplifier output tends to go positive. This causes the diode **83** to conduct. Since the input to the amplifier **79** is a virtual ground, the output is therefore clamped substantially at ground potential (plus the voltage developed across the low forward resistance of the diode **83**) for all values of the input V_{IN} less than the value of the bias voltage set by the potentiometer **81.**

If the value of the input V_{IN} is greater than the bias voltage value, thus giving a net positive input, the output of amplifier **79** goes negative. Diode **83** is cut off, but diode **84** conducts, connecting resistor **82** as a feedback resistor between the output and input terminals of the amplifier **79.**

Therefore, as the input V_{IN} varies from zero to its maximum, say −5v, the output of the threshold amplifier **74** remains substantially zero until the input V_{IN} reaches a value (the threshold or break value) determined by the setting of the (Break **1**) potentiometer **81.** Thereafter, the output increases linearly with a further increase of the input V_{IN}, with negative polarity and at a rate determined by the relative values of the feedback resistor **82** and the input resistor **78.**

The output of the threshold amplifier **74** is applied to a first summing junction **85** via a resistor **86,** and also to one end of a Slope **1** potentiometer **87.** The slider of the potentiometer **87** is connected to a second summing junction **88** via a resistor **89.**

The threshold amplifiers **75, 76** and **77** are similar to the amplifier **74** just described and are provided with respective threshold-setting potentiometers **90** (Break **2**), **91** (Break **3**) and **92** (Break **4**). Their outputs are applied to the first summing junction **85** via respective resistors **93, 94** and **95;** and also to respective potentiometers **96** (Slope **2**), **97** (Slope **3**) and **98** (Slope **4**). The sliders of the potentiometers **96, 97** and **98** are connected via respective resistors **99, 100** and **101** to the second summing junction **88.**

The input V_{IN} is applied to the first summing junction **85** via a resistor **102** and also to an "Initial Slope" potentiometer **103,** whose slider is connected to the second summing junction **88** via a resistor **104.**

A "Shift" potentiometer **105** is connected between ground and the −5v reference supply, and its slider is connected to the second summing junction **88** via a resistor **106.**

The first summing junction **85** is connected via relay contact RLIB to an input terminal of an amplifier **107** contained in the mode unit **51.** The second summing junction 88 is connected via relay contact RLIC to an input terminal of an inverting amplifier 108, whose output terminal is connected, via a resistor 109 to the said input terminal of amplifier 107.

The operation is as follows: ignoring for the present the second summing junction 88 and the amplifier 108, the output of the amplifier 106 depends on the contributions to the first summing junction from the input V_{IN} via resistor 102 and from the threshold amplifiers 74, 75, 76 and 77.

As the input V_{IN} increases from zero, current flows through resistor 102, but until the input V_{IN} reaches the respective break points of the threshold amplifiers, their outputs all remain zero. Consequently, the output of the amplifier 107 initially increases linearly with the input V_{IN} at a rate determined by the relative values of a feedback resistor 110 and the resistor 102, and with negative polarity.

When the input V_{IN} reaches the first break point, determined by the setting of the potentiometer 81, the first threshold amplifier 74 commences to give an output which increases linearly with a further increase of the input V_{IN}, and which is negative going. The current flowing via resistor 86 into the input terminal of the amplifier 107 is therefore of opposite polarity to the current flowing via resistor 102. The net effect is that the rate of rise of input current with increase of the input V_{IN} is reduced for values of the input V_{IN} above the first break point. Therefore, the rate of increase of the output of the amplifier 107 is similarly reduced.

As the input V_{IN} continues to increase it reaches successively the second, third and fourth break points determined respectively by the settings of the potentiometers 90, 91 and 92. At these points, the threshold amplifiers 75, 76 and 77 commence in turn to contribute to the input current to the amplifier 107.

The result is that a curve relating the output of the amplifier 107 to the input V_{IN}, neglecting the amplifier 108, comprises five linear sections whose slopes are progressively less. The break points at which the slope changes are selected by adjustment of the potentiometers 81, 90, 91 and 92.

Turning now to summing junction 88 and amplifier 108, it will be seen that the inputs to this junction comprise a fraction of the input V_{IN} chosen by adjustment of the potentiometer 103 and fractions of the outputs of the threshold amplifiers 74, 75, 76 and 77 selected respectively by adjustment of the potentiometers 87, 96, 97 and 98. Consequently, the curve relating the output of amplifier 108 to the input V_{IN} comprises five linear sections whose slopes are progressively less, and which individually are less than or equal to the slopes of the sections of the corresponding curve for the amplifier 107. The break points of the two curves are identical.

Since the output of the amplifier 109 is applied to the input terminal of the amplifier 107, the overall output of the latter amplifier is the difference between the two curves aforesaid. Consequently, the overall characteristic is a curve comprising five linear sections, both the slopes of the individual sections and the break points at which the slopes change being adjustable. In addition, the DC level of the characteristic may be varied by adjustment of the Shift potentiometer 105, which modifies the current into the summing junction 88.

The Break-potentiometers, the Slope-potentiometers and the Shift-potentiometers are adjusted to produce an overall characteristic which matches within close limits a crane rating curve.

A law generator unit 73 is provided for each separate rating curve. Each first summing junction 85 is connected via its respective relay contact RLIB to the input terminal of the amplifier 107, and each second summing junction 88 is connected via its respective relay contact RLIC to the input terminal of the amplifier 108. Selection circuits within the mode unit 51 ensure that only one of the relays, such as relay RLI, is energised at any one time, so that only one of the law generator units 73 is operational.

The selection circuits are arranged to energise the particular law generator unit appropriate to the desired mode of operation of the crane and may be automatic in operation. For example, sensors may be provided to detect when the outrigger booms are extended and blocked up. Only when the outrigger sensors are operated will a law generator for blocked modes of operation be brought into circuit. If the sensors are not operated, a law generator appropriate to free-on-wheel modes of operation will be selected.

Similarly, for cranes whose fly jib duty ratings are overridden by the main radius duty ratings for certain combinations of luff angle and boom extension, the boom extension and luff angle will be supplied to the selector circuits, and the law generator unit selected will depend on the values of these signals.

The true radius output TR provided by the amplifier 43 (FIG. 2) is supplied to the mode unit 51 and is connected to the inputs of those law generator units 73 which are selected when the crane is performing radius-related modes of operation. Similarly, the luff angle output θ provided by the amplifier 33 is connected to the inputs of those units which are selected for angle-related modes of operation. In each case, the connection is via the relay contact RLIA.

As previously mentioned, with reference to FIG. 2, the effective length of the boom when fully retracted (output E), and also the values of the constant outputs F and K will vary for different modes of operation. In each of the law generator units 73 there is provided a preset variable resistor 40 having one end connected to the OV line and the other to one side of a relay contact RLIE. The other side of the contacts RLIE of all the units 73 are connected together and to the negative input terminal of amplifier 38 (FIG. 2) so as to connect the resistor 40 of the selected unit 73 in the position shown in the dotted rectangle containing resistor 40 of FIG. 2.

Similarly, each law generator unit 73 contains preset variable resistors 54 and 56 connectible via respective relay contacts RLIF and RLIG to the positions shown for the dotted rectangles containing these resistors, respectively, in FIG. 2.

It is expected that a load indicating arrangement, as hereinbefore described, which provides an available lifting capacity indication in terms of total effective load at the hook, will have advantage over other forms of load indicating arrangement, such as described in our co-pending U.S. patent application Ser. No. 468,764, which provides an available lifting capacity indication in terms of the turning moment of the hook load about the boom pivot point, or in terms of actual hook load, because it can afford a greater dynamic range of operation for a wider range of crane sizes and thus has a more general application to cranes, or the like, of the different sizes. This may be explained as follows.

Consider first a crane which is rated to lift, say, 10 tons at a radius of 15 feet, but only 0.5 tons at a radius of 50 feet. The ratio of maximum hook load to minimum hook load is 10 tons to 0.5 tons (i.e. 20 : 1), while the ratio of maximum to minimum hook load turning moment is ($10 \times 15 = 150$) to ($0.5 \times 50 = 25$) tons feet (i.e. 6 : 1). Assuming the use in a load indicating arrangement of operational amplifiers having a dynamic range of 0–5v, then in the first case 5v = 10 tons and 0.25v = 0.5 tons, whereas in the second case 5v = 150 tons feet and approximately 0.8v = 25 tons feet. Assuming further that the operational amplifiers have a standing error voltage of 0.5mv, then 0.5mv in 5v gives a 0.01 percent error in the amplifier output and 0.5mv in 0.8v gives a 0.066 percent error in the amplifier output. If the overall arrangement is required to have less than 1 percent total error then these percentage errors might be acceptable, provided that the percentage errors of amplifiers throughout the arrangement did not accumulate to exceed the total percentage error.

However, in the case of a crane which is rated to lift, say 40 tons at a radius of 15 feet and 0.4 tons at a radius of 100 feet, the maximum to minimum hook load ratio is 100:1 and the maximum to minimum hook load turning moment ratio is ($40 \times 15 = 600$) to ($0.4 \times 100 = 40$) tons feet (i.e. 15 : 1). This second ratio of 15 : 1 approximates to the first ratio of 20 : 1 for the smaller crane, so that the percentage error for turning moment computation for the larger crane is now slightly greater than the percentage error for hook load computation for the smaller crane. Furthermore, the hook load computation for the larger crane now gives 0.5mv in 50mv (i.e. the voltage value for 0.4 tons), so that the percentage error in this instance is 1 percent which is the total percentage error allowed for the arrangement.

Consider now an arrangement according to the invention which provides safe load indications computed from total effective load at the hook. If the boom structure of the smaller crane weighs **4** tons, so that the average effective weight of the boom at the hook can be said to be **2** tons, then the total effective hook load ratio between maximum and minimum for the smaller crane is $(10 + 2) : (0.5 + 2) \approx 5 : 1$. If the boom structure of the larger crane weighs **10** tons, so that the average effective weight of the boom at the hook can be said to be **5** tons, then the total effective hook load ratio between maximum and minimum for the larger crane is $(40 + 5):(0.4 + 5) \approx 9 : 1$. From these figures, which are given by way of example only, it can be seen that an arrangement according to the invention would afford, on the assumptions made, a dynamic range of operation for either crane with an acceptable percentage error.

Also, with regard to improving dynamic range of operation, the following modification may be made in respect of the meter **58** (FIG. **2**c). This meter **58** indicates, as previously described, the difference between the outputs ($TEL + KL$) and SL.

For "heavy" duties of a crane, both the outputs TEL and SL will be large so that the difference between them can be large and the meter sensitivity will be adequate. However, for "light" duties of a crane, both the outputs TEL and SL will be small and the meter sensitivity may be insufficient to provide an indication between a "load" and a "no-load" condition. Therefore, to obtain substantially the same meter sensitivity the gain of the amplifier **50** can be divided by the output SL, with the meter **58** being calibrated in terms of percentage "safe working load" (within limits).

What we claim is:

1. A load indicating arrangement for a crane having a pivoted boom comprising, means for producing a first output signal representative of the total turning moment of the boom about its pivot in supporting a load, means for producing a second output signal representative of the horizontal distance between the boom pivot point and the load, means for producing a third output signal which is the quotient obtained by dividing said first output signal by said second output signal, said third output signal being thus representative of total effective load, a law generator unit for each mode of operation of the crane, each unit being adapted to produce a fourth output signal representative of the maximum safe load for the crane in the instant mode of operation, and means for comparing said fourth output signal with said third output signal to provide an indication of the actual crane load relative to the maximum safe load.

2. An arrangement as claimed in claim **1**, wherein said indication of the actual crane load relative to the maximum safe load is given by a meter calibrated in percentage of safe working load, said meter being coupled to the output of an operational amplifier having said third output signal and said fourth output signal applied jointly to an input terminal thereof and which has its gain divided by said fourth output.

3. An arrangement as claimed in claim **1**, wherein said indication of the actual crane load relative to the maximum safe load is given by a meter having a zero which is offset mechanically to a calibration point from which it is driven on the one hand into an overload region of its scale when said third output signal is greater than said fourth output signal and on the other hand into a safe region indicating available lifting capacity when said third output signal is less than said fourth output signal.

4. An arrangement as claimed in claim **1** further comprising, means for producing a fifth output signal which is determined by the boom deflection, and means for modifying the value of said second output signal by summing therewith said fifth output signal.

5. An arrangement as claimed in claim **1** wherein said first output signal producing means comprises, transducer means for producing an output signal which is a function of the reaction sustained by the boom supporting means in supporting the boom and any load suspended therefrom, and angle sensing means for modifying said output signal in accordance with the sine of the angle included between the boom supporting means and the boom thereby to produce said first output signal.

6. An arrangement as claimed in claim **1** wherein said means for producing a second output signal includes means for producing a sixth output signal which is representative of the length of the boom, means for producing a seventh output signal which is representative of the cosine of the boom luff angle, and means for multiplying said sixth and seventh output signals to derive the second output signal as the product thereof.

7. An arrangement as claimed in claim **6**, including means for producing an eighth output signal for modifying the value of said sixth output signal by an amount which is representative of the change in load radius error that occurs between maximum and minimum boom extensions when an offset fly jib is fitted, together with means for changing said amount as a function of boom luff angle, and means for selecting the value of said sixth output signal having regard to the effective boom length due to the offset fly jib.

8. An arrangement as claimed in claim **1** wherein the crane is adapted to provide at least two modes of operation and for modes of operation involving radius-related duties each law generator unit concerned is responsive to said second output signal, whereas for modes of operation involving anglerelated duties each law generator unit concerned is responsive to an output signal which is representative of the boom luff angle.

9. An arrangement as claimed in claim **8,** including switch means for selectively connecting said second output signal or said boom luff angle output signal to a law generator unit.

10. An arrangement as claimed in claim **1** further comprising, means for producing a fifth output signal which is representative of the position of the centre of gravity of the boom structure and varies with a change in boom length, and means for combining said fifth output signal with said third output signal to produce a corrected third output signal.

11. An arrangement as claimed in claim **10** further comprising, means for producing a sixth output signal which is representative of the weight of the boom structure, means jointly responsive to said fourth and sixth output signals to produce a seventh output signal, and means for comparing a given percentage of said seventh output signal with the output obtained from the comparison of said third and fourth output signals to provide an indication on the actual hook load relative to a percentage of the maximum safe hook load.

12. An arrangement as claimed in claim **11,** including means for combining said third, fifth and sixth output signals to provide a eighth output signal which is representative of actual hook load.

13. A load indicator apparatus for a crane having a pivotally mounted extensible boom comprising, means for producing a first signal representing the total turning moment of the boom and its load about its pivot, means for producing a second signal representing the horizontal distance of the load from the boom pivot point, means for combining said first and second signals for producing a third signal representing the total effective boom load, means for deriving a fourth signal representing the maximum safe load for the crane for the prevailing crane operating conditions, and means for comparing said third and fourth signals to derive an output signal indicative of the available lifting capacity of the crane.

14. A load indicator apparatus as claimed in claim **13** wherein said crane is adapted to provide at least two modes of operation, one of which is determined primarily by the load radius and the other by the boom luff angle, means for producing a signal representing the boom luff angle, said fourth signal deriving means including law generator means having input means selectively connected to receive said second signal or said luff angle signal in said one or the other modes of operation, respectively.

15. A load indicator apparatus as claimed in claim **13** further comprising means for producing a fifth signal representing the position of the boom center of gravity, and means for combining said third and fifth signals to correct the third signal as a function of the change in the boom center of gravity with a variation in the length of the extensible boom.

16. A load indicator apparatus as claimed in claim **13** further comprising means for modifying the second signal for fly jib operation of the crane comprising, means for producing a fifth signal representing the boom length, means for producing a sixth signal representing the boom luff angle, means responsive to said sixth signal to provide a correction thereto, means for producing a seventh signal representing the cosine of the boom luff angle, and means for combining said fifth signal, the corrected sixth signal and the seventh signal to derive the modified second signal.

17. A load indicator apparatus as claimed in claim **13** further comprising, means for producing a fifth signal representing the deflection of the boom under load, and means for modifying the second signal by combining therewith said fifth signal, said third signal being derived by combining the first signal with the modified second signal.

18. A load indicator apparatus as claimed in claim **13** further comprising boom support means, and wherein said first signal producing means comprises, means for producing a fifth signal which is a function of the reaction force sustained by the boom support means, means for producing a sixth signal representing the sine of the angle formed by the boom and the boom support means and means for combining said fifth and sixth signals to derive said first signal, and wherein the means for producing the second output signal comprises, means for producing a seventh signal representing boom length, means for producing an eighth signal representing the cosine of the boom luff angle, and means for combining said seventh and eighth signals to derive said second signal.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,913,690

DATED : October 21, 1975

INVENTOR(S) : Bernard D.F. Hutchings et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 3, line 37, cancel "hookload and";

line 38, after "load" insert -- and can --;

Col. 4, line 13, cancel ",," and insert -- , --;

Col. 9, line 29, cancel "on" and insert -- in --;

Col.10, line 1, cancel "V I_N" and insert -- V_{IN} --;

Col.11, line 7, change "106" to -- 107 --;

line 27, after "with" insert -- an --;

Signed and Sealed this

Fourteenth Day of September 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks

UNITED STATES PATENT AND TRADEMARK OFFICE

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