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GB A	2141020	GB	1444752
GB A	2135571	WO	84/03869

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A4F
E1H
Selected US specifications from IPC sub-classes B63B
E02B

(54) Remotely-operated vehicle for cleaning offshore structures

(57) A remotely-operated vehicle for removing marine growth from underwater surfaces of offshore oil rigs and gas production platforms comprises rollers (4A, 4B) rotatably mounted in steerable saddles (3A, 3B) set in frames (9A, 9B), propellor thrust units (1A, 2A, 1B, 2B) mounted outboard of the ends of the rollers, and movable arms (7A, 8A, 7B, 8B) at the ends of the vehicle carrying scraper wires (12A, 12B). Each roller, which may be hollow or filled with polystyrene spheres, may be provided with a motor drive. Underwater TV cameras (10A, 10B) and associated lighting may be mounted on the vehicle, as may steering position indicators (21A, 21B), and sensors giving depth, compass heading, and attitude in pitch and roll. Hydraulic fluid may be supplied via a pump at the control point, or for deep work an on-board electro-hydraulic power pack or electric motor drive may be used. The vehicle may be provided with a manipulator arm or a cathodic potential meter.

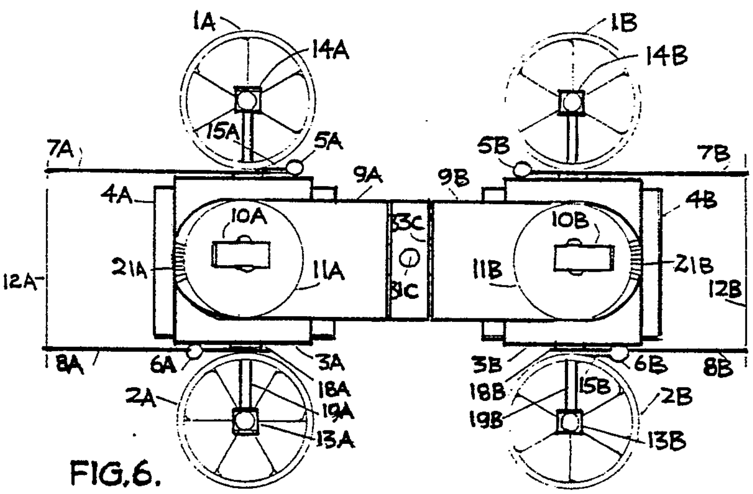

FIG.6.

FIG.7.

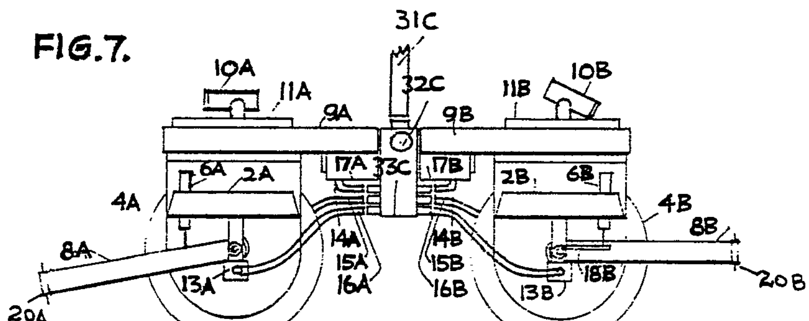

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FIG. 1.

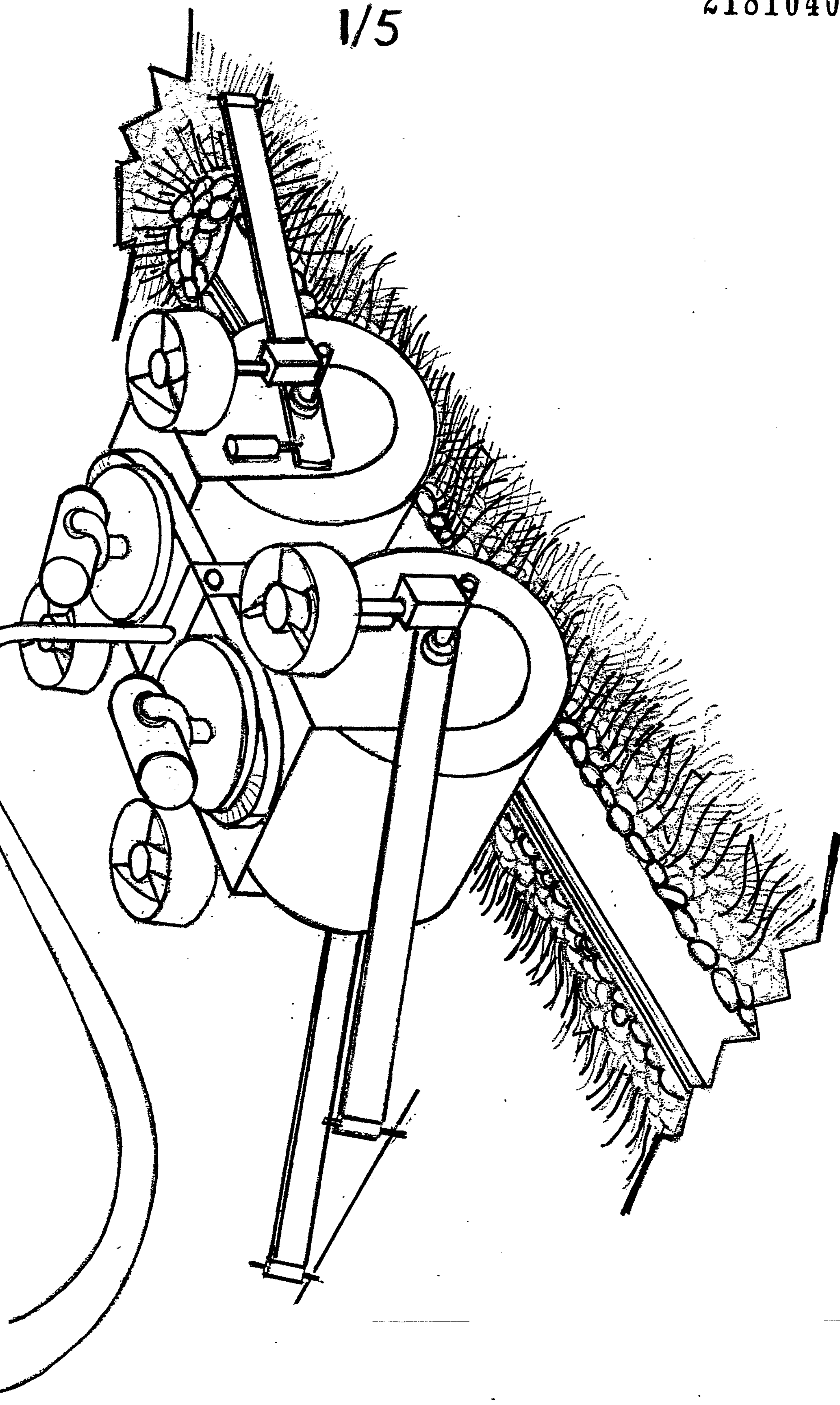


FIG. 2.

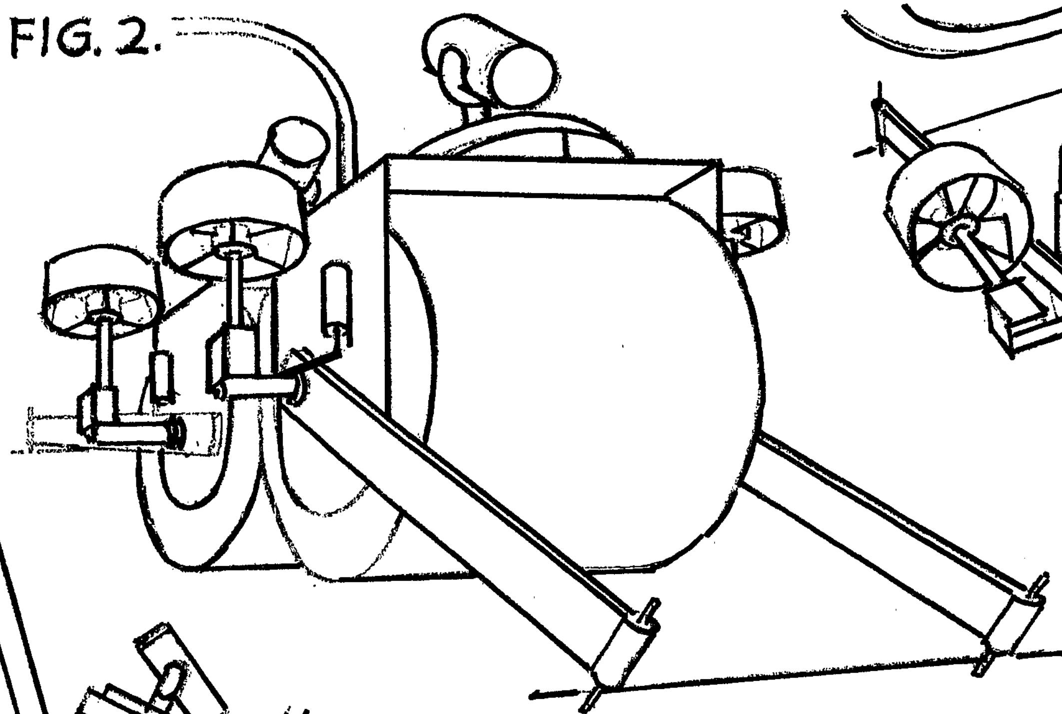
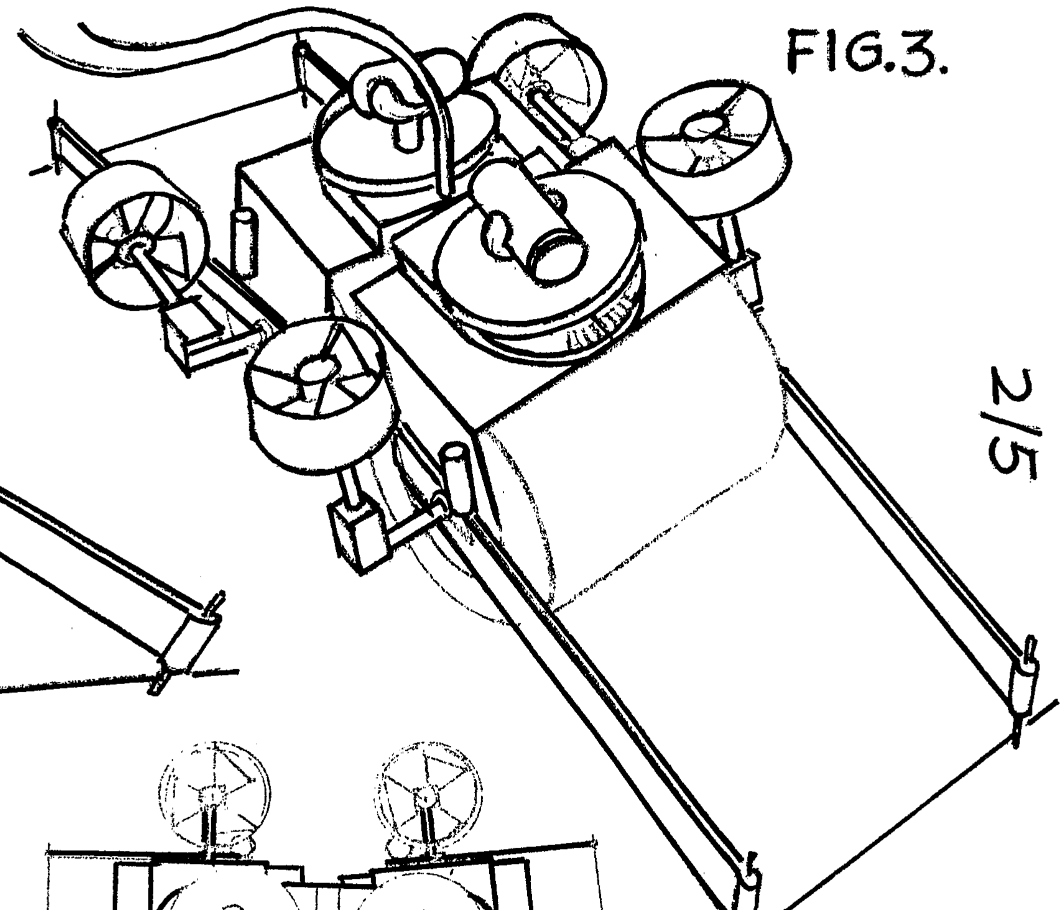


FIG. 3.



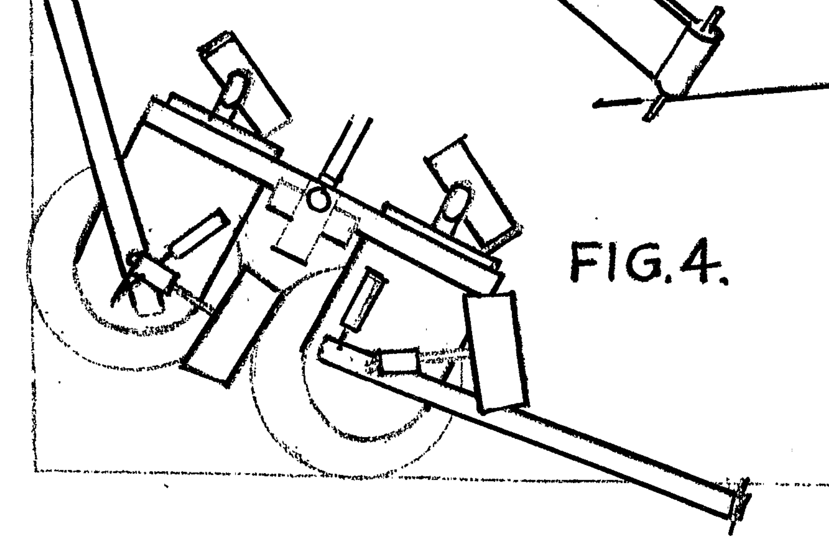


FIG. 4.

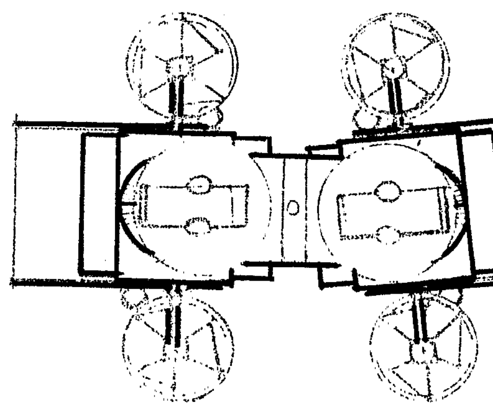
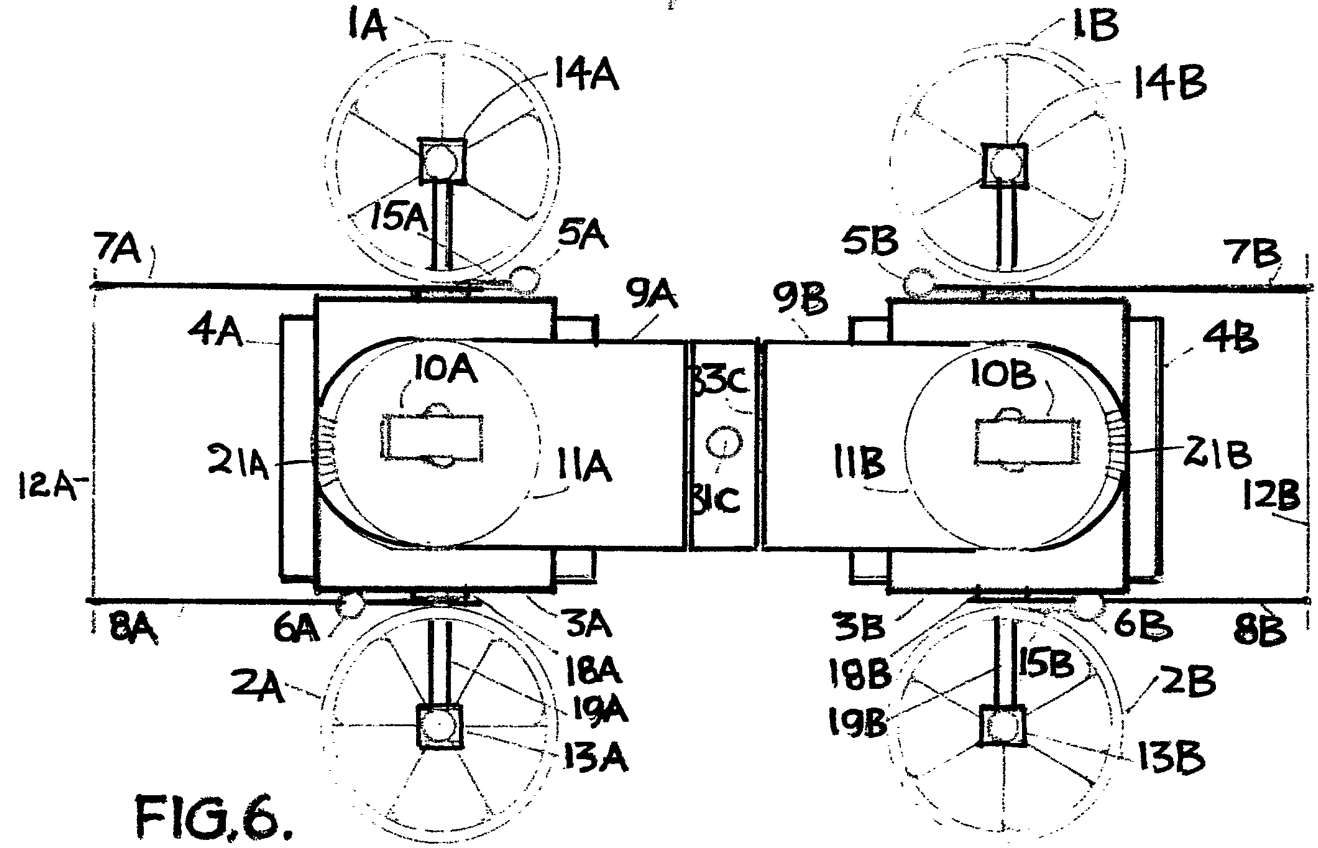


FIG. 5.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14A
1B
14B
15A
5A
5B
7A
7B
9A
9B
4A
4B
10A
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33C
21A
21B
11A
11B
31C
12A
12B
8A
6A
3A
3B
6B
8B
18A
18B
15B
2A
2B
19A
19B
13A
13B

FIG.6.

FIG.7.

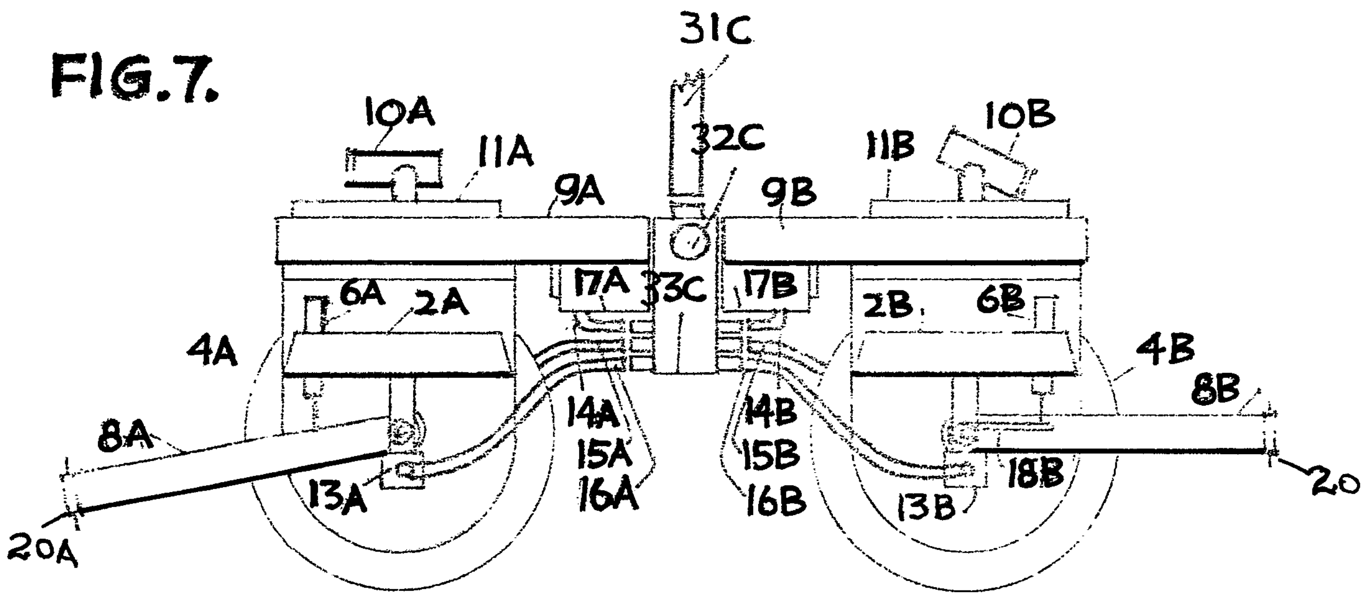
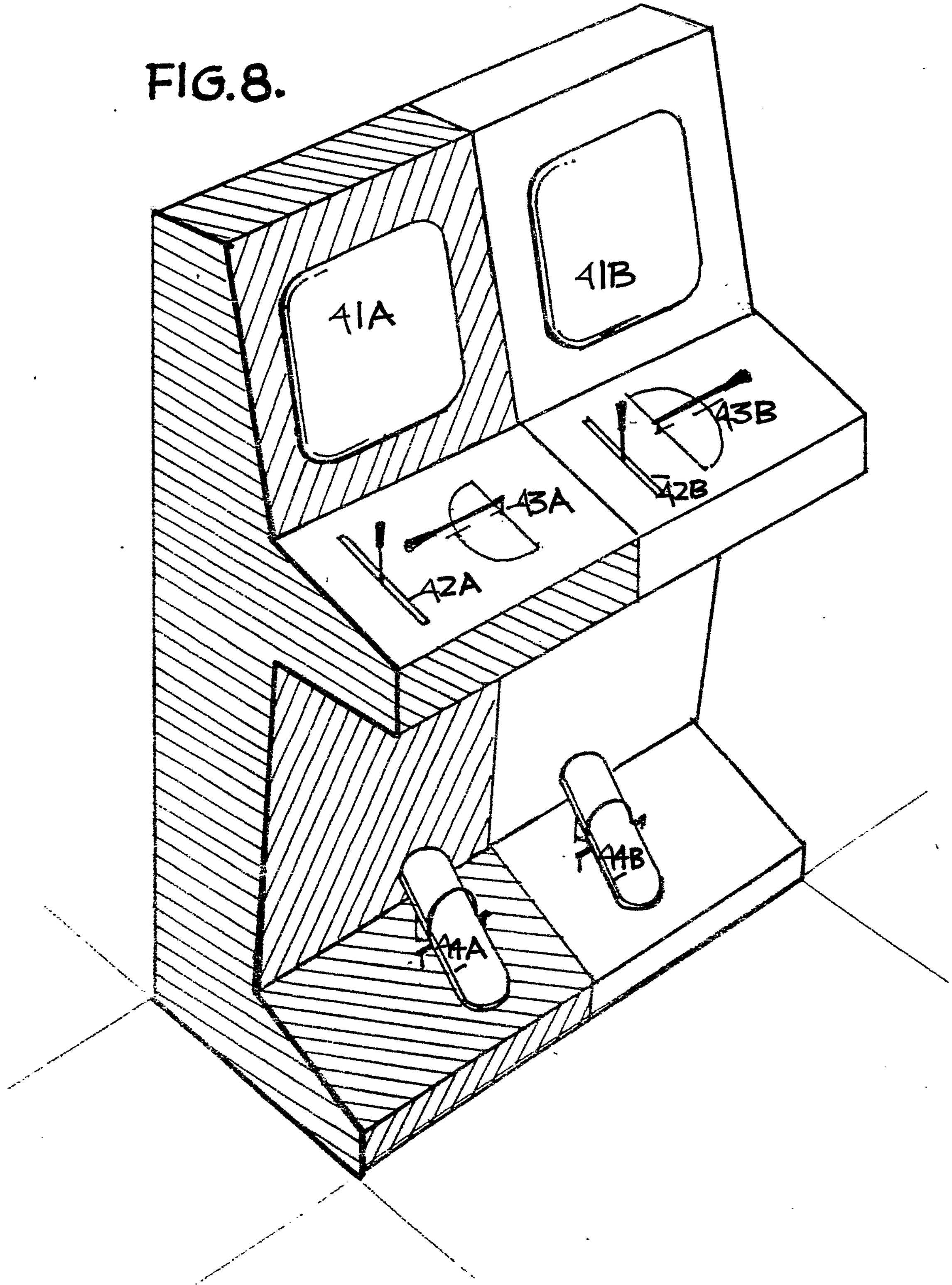

31C
10A
32C
10B
11A
11B
9A
9B
17A
33C
17B
6A
2A
2B
6B
4A
4B
8B
14A
14B
8A
15A
15B
18B
13A
16A
16B
13B
20A

FIG.8.



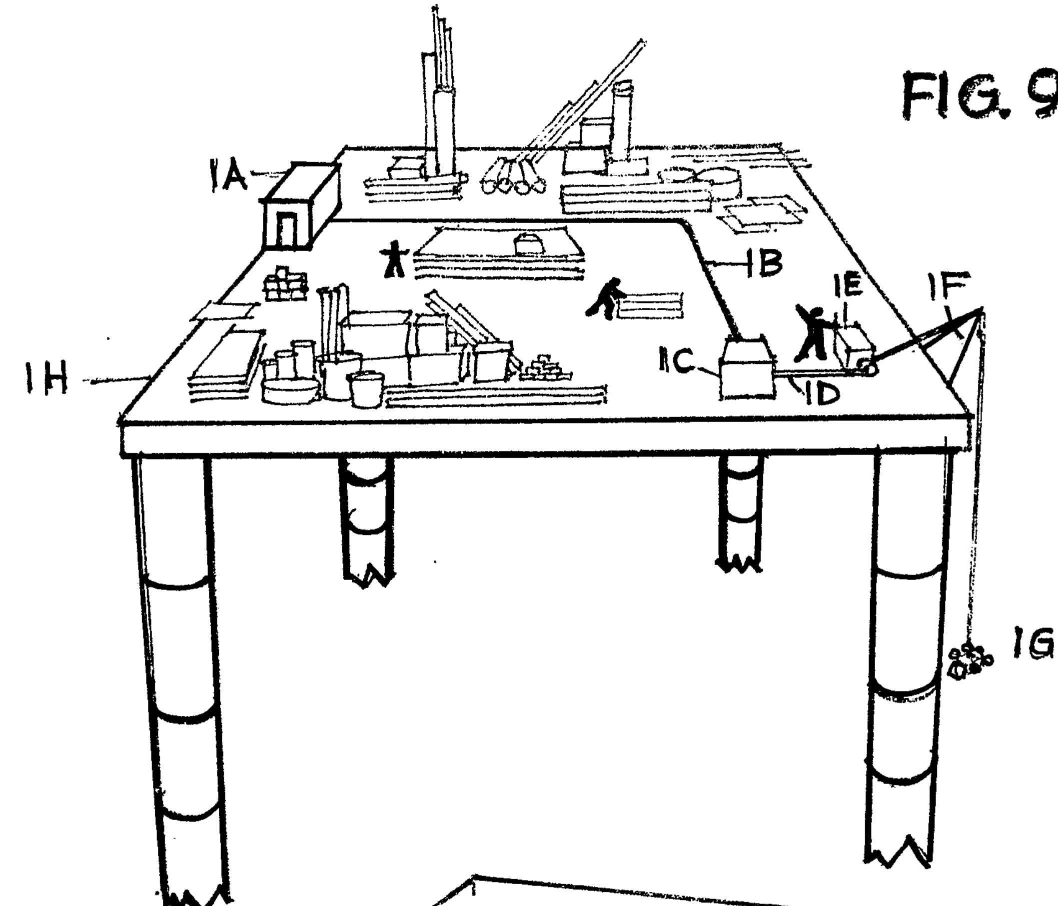


FIG. 9.

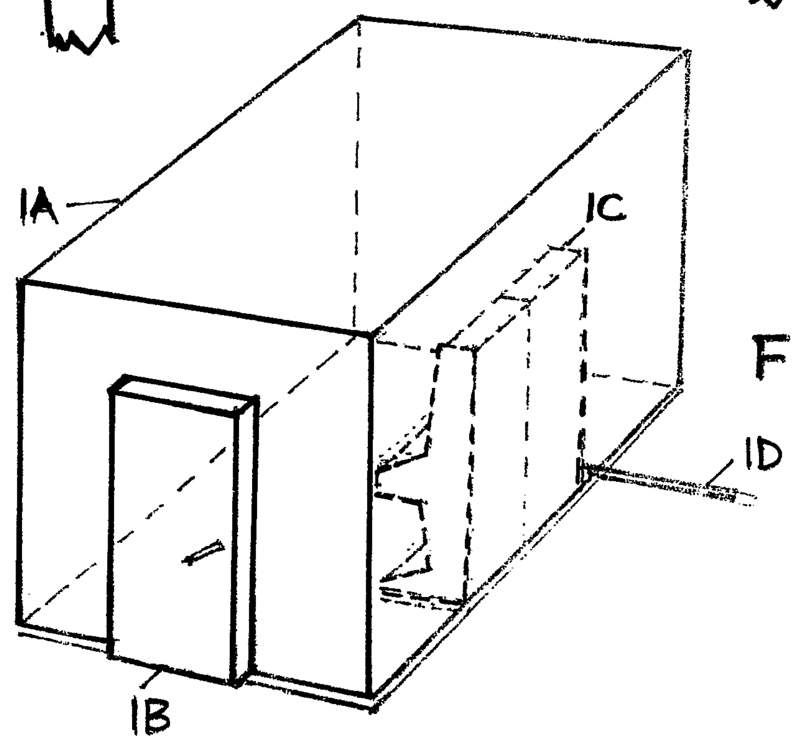


FIG. 10.

SPECIFICATION
Robby

Background of the Invention

1.0 This invention relates to remotely operated vehicles for use in cleaning marine contact surfaces. In particular it relates to cleaning off heavy growth of mussels and barnacles on gas production platforms in the southern part of the North Sea.

2.0 In the UK sector of the southern North Sea there are (as at September 1985) 86 gas production platforms installed or under development with a further 28 in the adjacent Dutch and Danish sectors. Still more are at an advanced stage of planning.

2.1 Mussel growth on the steel tubular members which form the structure of these platforms is rapid—0.1 metres thickness per year is common and up to 0.2 metres per year have been recorded. Growth is usually heaviest in the first 20 metres of water depth from sea level. Below this depth growth rates are less and the structure is less vulnerable to the effects of growth.

2.2 The accumulation of mussels etc. increases the cross-sectional area and drag coefficient of the structural members affected thus increasing the loading thereupon due to current and waves. In turn this adds to the stress on the structure and reduces the fatigue life of its vulnerable components to less than their design levels.

3.0 It is a requirement of operators, insurance companies and regulatory agencies alike that such growth is removed before it accumulates to a potentially hazardous extent. Rates of growth vary considerably between fields but on average each platform has to be cleaned overall about once every two years.

3.1 This weight-reduction cleaning is usually required from sea level down to a depth of about 20 metres. (See 2.1 above)

4.0 The southern North Sea is fairly shallow with platforms standing in 20 to 45 metres of water depth. This means that the platforms themselves are small relative to those in the northern North Sea.

4.1 For example the British Gas Corporation's "Rough" platform stands in 40 metres of water and has 8 main legs each 1 metre in diameter. The cross members are .45, .40 and .35 metres in diameter and the smallest tubulars in the structure are only .11 metres in diameter. The main deck is some 20 metres above sea level.

4.2 Thus the requirement is to clean growth from a variety of highly curved surfaces where the depth of growth may equal or exceed the radius of curvature. This contrasts with the much less demanding requirements of cleaning the hull of a ship or the face of a dam.

5.0 The southern North Sea is also subject to fairly strong tidal currents which typically reach 1 metre/sec (2 Knots) on spring tides. (It is worthy of note than an area where the average spring tidal current is 1 m/s has currents of .75 m/s (1.5 kts) or less for about half the hours in the year.)

5.1 When a current flowing normal to a cylinder passes over the surface of that cylinder it accelerates by about 50%. Therefore a general current of 1 m/s may give a velocity over a tubular of up to 1.5 m/s.

5.2 Such currents cause considerable drag forces on either a diver or an ROV trying to clean a tubular. The drag force on a smooth cylinder of 1 square metre in section subjected to a sea water velocity of 1.5 m/s normal to its axis is about 120 kgf.

5.3 In such a current turbulent flow around the tubulars and vortex shedding in their lee make it difficult for any floating object to hold a stable position in relation to the structure even if the sea is otherwise calm.

6.0 The relatively shallow depth of the seabed and the speed of the currents cause turbid conditions and poor visibility. Forward visibility, whether through the eye of a diver or the lens of a TV camera, may be as little as 2 metres.

7.0 To date cleaning has been done by divers who work only during periods of slack water—that is for about 4 to 6 hours out of 24. Diving spreads are costly (circa £7,000 per day) and so the cleaning process is expensive as well as time consuming.

7.1 New regulations by UK Department of Energy which come into force in October 1985 will further restrict the conditions under which divers can operate in the North Sea and further add to the time and cost described in 7.0 above.

7.2 By reason of the operating problems described in this note existing ROV's and cleaning mechanisms have not been successful in doing this work.

8.0 This invention provides an ROV which is capable of removing at least 90% of the marine growth on a production platform as described above in a manner which is reliable, rapid and economic.

Summary of the Invention

9.0 ROBBY is a remotely-operated vehicle whose principal role is to remove heavy (up to .3 metres thickness) marine growth such as mussels and barnacles from offshore oil or gas production platforms and to do so especially where the platform members are of relatively small diameter (less than 1 metre), the current is relatively fast (up to 1 metre/sec) and the visibility is poor (down to 2 metres).

9.1 It travels on the underwater surface of the structure and adheres strongly to it by means of the self-centring reaction of four propellor thrusters thus ensuring stability and visibility in relation to the part being cleaned.

9.2 It runs on twin articulated and steerable rollers and is propelled forward or backwards by vectoring its thrusters. Thus it can travel in a stable manner with accurate control along or around an underwater tubular of whatever diameter and at whatever angle or attitude.

9.3 Its suspension and drive allied to its means of steering enable it to travel over the whole of the underwater structure of the platform and to transfer from one structural member to another as required.

9.4 It is small and compact in relation to its grip and drive force thus enabling it to overcome the drag caused by a fast current.

9.5 It removes growth by means of flexibleundercutting scrapers (one forward and one aft) which adapt themselves to the radius curvature of any tubular member.

9.6 Its scrapers are operated by the movement of the ROV along the tubular (in a manner analogous both to a cheese wire and to a snowplough) thus giving a simple and robust device able to withstand the adverse environment associated with mussel cleaning.

9.7 It carries the minimum of equipment on-board and so is light and easy to launch and recover. Thus it can be operated from the platform being cleaned. This saves the cost of an attendant vessel.

9.8 The preferred means of operation is from the platform but if the production company so wishes the ROV can readily be launched and operated from a support vessel adjacent to the platform.

9.9 ROBBY is simple and of relatively low cost so that if, by ill-chance, it is lost or damaged the resultant loss is small.

Detailed Description of the Invention

10.0 Note: Reference is made throughout this description to drawing 3/5 (of the ROV itself and numbers 1 to 33) and to drawing 4/5 (of the control console and numbers 41 to 44). The ROV is symmetrical fore and aft. The suffix "A" refers to the "front" sub-frame and its associated components and controls and the suffix "B" to the "rear" likewise. Drawings 1/5 and 2/5 are provided for general illustration.

10.1 The running gear of the invention comprises two rollers (4A & 4B) each being free to rotate about a sleeve axle (18A & 18B) set in a steerable saddle (3A & 3B). Each saddle is set in a frame (9A & 9B) in which it can pivot under control of the steering actuator (not shown). Both frames are connected together by a longitudinal pivot (17A & 17B) such that they are free to rotate about the longitudinal axis relative to one another but are otherwise fixed relative to one another.

10.2 Grip is provided by each roller having a propellor thruster unit (1A, 2A & 1B, 2B) fixed on an inner axle (19A & 19B) at either end outboard of the rollers. Each thruster propellor is driven by a hydraulic motor *or* an electric motor (13A, 14A & 13B, 14B) and rotates in the plane of the frame so as to discharge water "upwards" in relation to that frame. The reaction of the water discharge thrusts the roller against the tubular or other surface on which it stands. (This happens irrespective of whether the ROV is above, underneath or on the side of the tubular.) The total grip of the ROV is about 30 kgf per kw of power output of the thruster motors.

10.3 Each pair of thrusters has one left-handed (1A & 2B) and one right-handed propellor (1B & 2A) so that they contra-rotate and therefore generate no nett reaction torque on the frame. Each propellor is surrounded by a plastic nozzle to protect it and enhance its thrust.

10.4 The thrusters produce a self-centering action which causes each roller to take up a stable position with the tubular on which it stands being at the mid-point of the roller. When the ROV is spiralling around a tubular the longitudinal pivot between the frames allows each roller to accommodate itself to a central position on the tubular. (See Fig. 3 on drawing 2/5)

10.5 The ROV is, like a tramcar of old, symmetrical fore and aft and can work and travel equally well in either direction.

10.6 The materials of construction for the ROV are light alloy and plastic composite.

10.7 The rollers are hollow, open to the water and have a hatch at the side into which sealed polystyrene spheres .04 metres diameter (not shown) may be inserted. Each roller may thus be given variable bouyancy.

11.0 The ROV is propelled forward or backwards either by motor drive to each roller *or* by vectoring the thrusters forwards or backwards in relation to the frame *or* by a combination of these two means. The first method gives precise control of motion but depends on friction between roller and structure for propulsion. The second gives less precise control but ensures propulsion independent of friction. The third method gives optimum performance but with greater weight, complication and cost. The second method is adopted in this embodiment and is described further at 18. below.

12.0 Each roller saddle can steer left or right by 30 degrees in relation to the frame. The steering action is produced by linear *or* rotary actuators which may be powered hydraulically *or* electrically (not shown). The front, the rear or both rollers may be used for steering. Tight turns are produced by steering both rollers in the opposite sense. Crabwise side motion is produced by steering both rollers in the same sense. The steering allows the ROV to drive along the various members of the structure as if on a road network. There is a more difficult task in moving from a horizontal frame to a vertical conductor and this is described at 18.3 below.

13.0 The "eyes" of the ROV are two underwater TV cameras connected to two display screens at the control point. One camera (10A) is on a rotating plate (11A) connected to the front saddle and one on the back (10B) on a similar rotating plate (11B) each looking outward from the frame. Each camera follows around as its roller steers and each can be tilted by an actuator *or* pre-set to an appropriate angle. The latter is described in this embodiment. The cameras are robust, compact, wide-angle, black and white models which use a charge-coupled imaging device instead of a tube.

13.1 Each camera is fitted with a light (not shown) immediately above the camera. These lights are circa 250 watt and use blue-frosted lenses to minimise back scatter of the light. Power for the light is taken from the surface through the umbilical cable (31C).

13.2 Each camera can see the position of the scrapers (12A & 12B) central in its view. Each can see the graduated indicator dial (21A & 21B) giving steering position in the lower part of its field of view. The position of the thrusters is monitored by potentiometers (not shown) fitted to the axles and registers at the control console. (See drawing 4/5).

13.3 Additional sensors (not shown) giving depth, compass heading and attitude in pitch and roll may also be fitted.

14.0 The scrapers which do the cleaning are mounted one each at the front and rear. Each consists of two arms (7A, 8A & 7B, 8B) which are raised or lowered by an actuator (6A & 5B) and which carry at their far end a flexible scraper (12A & 12B). At the roller end the arms are inter-connected by a sleeve (not shown) which runs over the axle carrying the thrusters and causes both arms to go up or down in unison. The sleeve is the axle upon which the roller rotates. The actuator is anchored to the steerable saddle and the scraper steers as the saddle and roller assembly is steered.

14.1 The scraper (12A & 12B) consists of a 2 mm diameter high tensile steel wire. As this is lowered against a tubular it adapts to the radius and, as the ROV moves forward, undercuts the mussel or other growth thus cleaning the structure. Alternatively the ROV may run on the uncleaned pipe and tow the scraper behind it cleaning as it goes.

14.2 The arms normally extend 0.5 metres beyond the roller but longer ones may be fitted for special duty. They are made of spring steel 3 mm thick and tapered on the lower edge so that they penetrate readily into the mussel growth.

14.3 The cutting wire (12A & 12B) is anchored at the end and at the bottom of either arm on a small swivel (20A & 20B). When it is undercutting the wire takes on a double curvature; one normal to the tubular and corresponding to its radius and one parallel to the tubular being the "catenary" curve due to the undercutting force. The swivel helps the wire accommodate to this curvature. (See Fig. 1 on drawing 1/5).

14.4 The drive force needed for undercutting mussels is about 2 kgf per cm width of cut. For barnacles or mussels undergrown by barnacles it is about 5 kgf per cm width of cut. For soft growths it is less than 2 kgf per cm of cut. Thus for a width of cut of .4 metres the required force is about 80 kgf for mussels only and less for soft growths but about 200 kgf for barnacles. So the drive arrangements must provide up to 200 kgf of thrust for cutting.

14.5 With a total down thrust of 720 kgf (see 15.2 below) 200 kgf of forward thrust is produced when both pairs of thrusters are vectored to about 16 degrees. At that angle the grip force will still be some 690 kgf. Alternatively the 200 kgf can be produced with one thruster pair at 34 degrees vector while the other remains in the full grip position. The grip of the vectored pair is reduced from 360 kgf to 300 kgf.

14.6 Additional forward thrust is needed to overcome fluid drag on the ROV and on the umbilical. At the normal ROV speed of about 0.3 m/s and in still water this drag is slight in relation to the cutting force. If there is a strong current those forces may be similar to the cutting force. It may then be necessary to cut with the current and run back light against it.

14.7 In circumstances where the standard of finish needed is better than can be had by linear scraping alone it can be improved by oscillating the scraper. This is done by an additional lateral jack (not shown) on each scraper mounting. The jack is valved to stroke to and fro automatically. It is connected to one scraper arm and makes it oscillate left and right by .05 metres. It is not normally fitted to Robby.

14.8 As well as cleaning off growth one or both of the scrapers (12A & 12B) can act as brakes either to hold a steady position or to assist in controlling the movement of the ROV.

14.9 They can also act as buffers when the ROV comes up against another tubular at the end of a cutting run. The springiness of the arms enables them to absorb the slow speed impact.

15.0 In this embodiment the power supply is from a hydraulic pump at the control point. This reduces on-board weight, cost and complexity but gives a thick umbilical (31C) which has a correspondingly high drag. It is limited to an umbilical length of about 100 metres. For deep work an on-board electro-hydraulic power pack may be fitted *or* electric motor drive used. Later embodiments may be fitted with electric thrusters which act directly on the sea water without mechanical drive.

15.1 In this embodiment the pump at the control point is driven by a 45 kw electric motor and delivers 35 kw of hydraulic power. That is 125 litres/minute at 170 bar. Up to 5 litres/minute are bled off to drive the winch. (See 20 below). The hydraulic coil is taken to the ROV via a 19 mm (3/4") i/d hydraulic line and returned via a 25 mm (1") i/d line. The pressure drop in the outgoing line is 10 bar, that in the return is 2.5 bar and in the fittings also 2.5 bar. Thus the nett pressure available at the ROV is 155 bar and the flow is 120 litres/min so 30 hydraulic kw are delivered to the ROV.

15.2 The ROV thruster motors (13A, 14A & 13B, 14B) absorb 7.25 kw of hydraulic power each and deliver 6 kw of shaft power each to their respective propellors. This gives a thrust of 180 kgf i.e. 0.72 tonnes total grip for the ROV. The thrusters are permanently connected to the hydraulic supply and run continuously so long as that supply line is live. Their output as a whole can be controlled by varying the supply pressure from the pump.

15.2.1 The changes in flow and pressure caused by the intermittent operation of the winch or the actuators are small relative to the total flow and merely cause small changes (+/−3%) in the thrust available.

15.2.2 In this embodiment the o/d of each propellor is .25 metres and the o/d of each nozzle is .32 metres. The clearance between the edge of the nozzle and the edge of the frame is .08 metres.

15.3 The actuators tap off their hydraulic supply from two pressure compensated valve pods (not shown) on the ROV. Each pod has 4 control valves; two for vectoring and one each for steering and scraper operation. They are located centrally on their respective sub-frames alongside the longitudinal pivot. Each pod controls the functions for its 'own' roller.

15.4 The valves may be servo *or* proportional *or* simple three-way solenoid-operated. The last alternative which is the simplest and cheapest but gives the least convenient control is described in this embodiment. Whatever the valve type the electrical control cables go via the umbilical from the control point to the ROV.

16.0 In this embodiment the umbilical cable (31C) carries two lightweight 'Synflex' hydraulic lines of 19 mm and 25 mm i/d, two TV cables, eight control wire pairs, two lighting wire pairs and spare lines for sensors etc. It has a 4 mm o/d stainless steel wire rope at its core which bears the weight of the ROV. It is 100 metres long. Its diameter is .075 metres. (Where electric motor drive is used the umbilical is lighter and flexible but the ROV is heavier).

16.1 In air the umbilical weighs 4.3 kg per metre length. It weighs 0.4 kg/metre in water.

16.2 In a 1 m/s (2 kts) current it has a drag of some 4 kgf per metre run of cable at right angles to the current. This drag falls to 1 kgf/m if the current speed is 0.5 m/s (1 kt).

16.3 In a wind speed of 15 metres/sec (30 kts) the drag on the umbilical due to the wind is about 1.2 kgf per metre run.

16.4 The joining of the umbilical to the ROV is important. Because the umbilical is thick it is vital that it does not exert a moment on the ROV due to its stiffness. (The moment caused by the tension due to umbilical drag is inescapable.) The umbilical is attached to the 'umbilical fulcrum' (33C) which turns on the longitudinal pivot axle which connects the two sub-frames.

16.5 The stiffness moment is obviated by allowing the umbilical to stream from the ROV at the natural angle produced by the tension forces. This means that the fulcrum must give freedom of angle to the umbilical in both horizontal and vertical planes.

16.6 The final metre length of the umbilical is split into its component parts. That is, two hydraulic lines, two camera lines and two sets of control wires. The hydraulic lines are the biggest and stiffest and their treatment is the determining factor. The final metre of the umbilical hydraulic lines and the on-board hydraulic lines are of conventional rubber and metal braid material for optimum strength and flexibility.

16.7 Freedom in the vertical plane is achieved by attaching the hydraulic lines to the umbilical fulcrum which is free to turn in the vertical plane. The two lines are attached on the fulcrum at 180 degrees apart. With the umbilical streaming vertically above the ROV the two incoming lines are horizontally opposite each other.

16.8 Freedom in the horizontal plane is achieved by attaching the umbilical lines to the fulcrum via swivelling joints. These are free to swivel through 180 degrees in the fore and aft direction.

16.9 The fulcrum is .36 metres wide and turns on a pivot .04 metres in diameter. The centre of rotation is .44 metres above the roller bottoms.

16.10 The on-board hydraulic lines come off from the centre droparm of the fulcrum below the pivot with three pairs of lines forward and three aft (14A, 15A, 16A & 14B, 15B, 16B). They are manifolded to the main pressure or return line as appropriate. On each frame one pair goes to the left hand thruster, one to the right hand thruster and one to the valve pod.

16.11 These lines are on rotating joints and have sufficient free length and flexibility to accommodate 180 degree rotation of the fulcrum. They need regular inspection and replacement as necessary.

16.12 The camera cables (not shown) run directly to their respective cameras. The control wires (not shown) go likewise to the two valve pods. Spare lines are attached directly to 'dead' sockets on board the ROV.

17.0 The diameter of the rollers is such that when the thrusters are vectored the circumference they trace out is within the circumference of the roller. The roller surface has circumferential ribbing to improve its side grip and steering force.

17.0.1 In the embodiment here described the rollers are .4 metres wide by .4 metres o/d. They are set at .8 metre centres i.e. .4 metres between faces. The overall length of the ROV body is 1.2 metres and its width overall is 1.2 metres. With both scrapers down the loa is 2.2 metres. Its deck height is 0.5 metres and its maximum height with a scraper full up is 0.9 metres.

17.1 The ROV complete weighs approximately 130 kg in air an its bouyancy is adjusted so that it weighs about 50 kg in sea water (52 kg in fresh water). The centre of bouyancy and the centre of gravity are both .25 metres above the roller bottoms. When lowered into water the ROV sinks with the frame horizontal.

17.2 The substantial weight of the ROV in water means that when it is upside down its nett grip is $720-50=670$ kgf. When it is side on the grip is 720 kgf but there is an overturning moment of $50\times.25=12.5$ kg-metres due to the ROV's weight. This is compensated by the rollers running slightly off centre on the tubular. The amount of off-centre resulting is $12.5/720=.02$ metres. The sideforce is blanced by the friction between the rollers and the tubular. The required coefficient of friction is $50/720=.07$.

17.3 In a general current of 1 m/s (2 kts) the ROV may experience a local current of 1.5 m/s in the worst case. This will occur when it is on the top or bottom of a tubular with the general current at right angles to that tubular. The umbilical will experience the 1 m/s current. The ROV will then have to balance both the sideforce and the overturning moment caused by its own drag plus that of the umbilical.

17.4 In a general current of 1 m/s the worst case occurs when the ROV is at the lowest cleaning depth (20 metres) working upside down on a member at right angles to the current. Some 25 metres of umbilical are deployed at rightangles to the current.

17.5 The ROV itself experiences a local current of 1.5 m/s giving a side drag of 114 kgf (area .6 sq. metres and c.d. 0.8) acting at a height of .25 metres so causing an overturning moment of 29 kg-metres. The umbilical (which is in the 1 m/s current) has a drag of 100 kgf which, assuming it is all borne by the ROV, causes a sideforce of 100 kgf and an overturning moment of $100\times.44=44$ kg-metres.

(See 16.9 above.)

17.6 In 17.5 above the total sideforce is 214 kgf and the total moment is 73 kg-metres. The grip force is 670 kgf as the ROV is upside down. The coefficient of friction needed to balance the sideforce is 214/670=.32. This friction is obtainable when working on hard growth. It exceeds that obtainable on soft growth. The off-centre on the rollers is 73/670=.11 metres. Thus the ROV is running nearer to the edge of the rollers than to their centre.

17.7 The situation outlined in 17.6 above approaches the worst case attainable when the ROV is static in a 1 m/s general current. As cutting motion is at right angles to the current it adds little to the drag forces. However, the situation is beyond the limits for comfortable working. In a general current of 0.75 m/s (1.5 kts) the roller off-centre is .06 metres and the required coefficient of friction is .18. This is within comfortable working limits. Clearly it is advantageous is such work can be confined to those stages of the tide when the current is .75 m/s or less.

17.8 There are two modes in which the ROV can lose position; toppling or sliding. The sliding mode is undramatic in that the ROV slides around the tubular and away from the current so as to reduce the side loading. The roller offset on the tubular is also reduced. Both rollers may slide or the more lightly loaded one only may slide.

17.8.1 The toppling mode, by contrast, represents a 'catastrophic' failure where position and control are lost entirely. The required action is to cut off hydraulic power immediately and attempt to recover the ROV by careful winching.

17.9 In practice increasing sideforces and the consequent toppling moments manifest themselves by an increasing offset of the tubular from the centre line of the rollers. If the offset gets to halfway between the centre and the edge of the roller this is a signal to the operator to 'back-off'.

17.9.1 The immediate action is to move into the lee of the tubular so as to shed the ROV sideload and convert the umbilical drag to a straight pull force instead of a toppling one. Then the ROV may move to an easier work location e.g. to a member which is in line with and not across the current, or it may just 'loiter' until the current speed has abated.

17.10 When the ROV is on a tubular which is in direct line with the current and assuming the parameters of 17.4 above apply the forces acting are as follows. When the ROV is stationary the drag force on the umbilical is 100 kgf. The drag-force on the ROV is 40 kgf. (area of .64 sq. metres and c.d. of .6). Thus to hold its position the ROV's thrusters need to give 140 kgf of thrust. This corresponds to a vector angle of 11 degrees. That reduces the normal grip force from 720 kgf to 706 kgf. This is reduced further to 656 kgf when the ROV is upside down.

17.11 The lengthwise overturning moment which acts about the roller base is 40×.25+100×.44=54 kg-metres. This is balanced by the grip force on one roller being reduced and transferred to the other roller. The force transferred is 54/.8=68 kgf. When the ROV is upside down the grip force per roller is 328 kgf so the 'light' roller will reduce to 260 kgf grip.

17.12 In the circumstances of 17.10 and 17.11 above but with the ROV moving into the current at .3 m/s (not cutting) the total force needed rises to 237 kgf and the thruster vector to 19 degrees. The force transferred rises to 115 kgf and the grip on the 'light' roller falls to 213 kgf.

17.13 Cutting with the current in the circumstances above is a matter of lowering both scrapers and letting the current force, plus some vector thrust if needed, push the ROV along and do the cutting.

17.14 If is evident from this section that it is desireable to work at 20+ metres depth only when the current velocity is .75 m/s or less—which obtains for about half the time. (See 5.0 above) Working thus reduces the forces and turning moments to about 65% of those when the current is 1 m/s. The high rate of work available from the invention makes this selective operation a practical proposition. (See 23.0 below).

18.0 Forward thrust and thence forward motion is produced by vectoring the thrusters on either or both roller axles. The appropriate signal from the "throttle" (42A & 42B) at the control point gives an electrical signal to the control valve which supplies hydraulic pressure to the actuator (5A & 6B) and causes the thruster pair to vector backwards thus producing a forward thrust. The amount of forward thrust is nearly proportional to the angle of vector. (See 14.5 above.) Further control of movement is obtained by using either or both scrapers as brakes. 'Rearward' motion is merely 'forward' motion as seen from the other end of the ROV and is produced and controlled in like manner.

18.1 Sideways motion is produced by steering both rollers in the same sense while the ROV moves forward. This is used to enter a new 'swathe' when cutting growth.

18.2 The ROV surmounts an outside right angle by driving across it diagonally at about 45 degrees. It then crosses without problem.

18.3 Traversing an interior right angle e.g. moving from a horizontal conductor frame up or down one of the vertical conductor pipes, is a difficult manoeuvre. The sequence of action is as follows. (See Fig. 4 on drawing 2/5).

18.3.1 Set the front scraper (12A) to the fully up position so that the front roller is clear to push against the upright pipe. Set the rear scraper (12B) to the 45 degree position to act as a steadying device.

18.3.2 Thrust the ROV forward so that the front roller (4A) pushes against the upright pipe. Set the rear thrusters (1B, 2B) to the pure grip position. Then vector the front thrusters (1A, 2A) slightly below the horizontal (to about 100 degrees) so that they give maximum forward thrust but also some lift off the horizontal frame and up the vertical pipe. As the ROV starts to climb the vertical pipe progressively reduce the vector angle of the front thrusters. (See Fig. 4).

18.3.3 At the 45 degree position the rear scraper strikes the horizontal tube and acts as a brake. This gives a pause, if required, to adjust the vector of the front thrusters. This done the rear scraper is raised and the ROV continues up onto the vertical pipe.

19.0 Since the ROV depends on propellor thrust for grip it can only work when submerged in water. On the other hand significant growth extends up the structure to about mean sea level and the ROV must be capable of cleaning to that level.

19.1 Offshore platforms are so designed that they do not have horizontal framework at mean sea level. On the gas production platforms described above the first submerged horizontal framework is some 7 metres below MSL. Therefore the tubulars at or near MSL are either vertical or diagonal.

19.2 Cleaning at sea level is achieved by taking advantage of 19.1 above and making the task a priority for the first forecast calm day (or night). For the sortie long arms (to replace 7A & 8A) are fitted to one frame of the ROV. These may be 2 or 3 metres long as required. The ROV moves up the tubular to be cleaned and uses the long arms to clean to sea level while itself remaining submerged. If there is a significant rise and fall of tide advantage is taken of this and the work is done whilst the tide is high.

20.0 The "topsides" of the invention consist of a conventional but half-size ROV control cabin rated for operation in explosion hazard areas together with the hydraulic power pack, the umbilical holding drum, the umbilical winch capstan, and the A-frame for deploying the ROV. With the exception of the control console (see 20.1 below) these are all conventional items of equipment.

20.1 The control console (see drawing 4/5) in the cabin is different from that of a conventional ROV. There are two TV screens (41A & 41B) which display the pictures from the fore and aft cameras. The left hand screen shows the picture from the "front" camera looking to the left. The right hand one shows that from the "rear" camera looking to the right. At the inner edge of each display is a view of the on-board dial (21A & 21B) showing the steering angle for that roller. Each scraper is in direct camera view.

20.2 Information applicable to the ROV as a whole such as depth or attitude is, if reported, displayed in digital form on the top line of the left hand TV screen. Standard information such as date, time etc is displayed on the top of the right hand screen. Each screen is connected to a VHS video-recorder so that a full record of each sortie can be made.

20.3 All controls for the "front" (A) sub frame fall to the left hand or foot of the operator and all those for the "rear" (B) sub-frame to the right hand or foot.

20.4 The foot pedals (44A & 44B) work the scrapers (which are also the brakes). The pedals are centre hinged for both up and down motion. A downward movement of the top of the pedal causes the corresponding scraper to move downwards and an upward one, upwards. When the scraper has reached the required angle returning the pedal to its spring-loaded mid-point stops the scraper and holds it in position.

20.5 Each steering jack is controlled by a small tiller (43A & 43B) rotating in the horizontal plane and causing the roller to steer in the same sense as its tiller. A move to the right produces steering motion to the right and vice versa. Return of the tiller to its spring-loaded mid point causes the steering to hold the required angle of turn (if any) when that has been reached.

20.6 Each pair of thrusters (1A, 2A & 1B, 2B) is vectored by a "throttle" lever (42A & 42B) similar to the steering tiller but acting forward and back in the vertical plane. Movement of the throttle forward causes the thrusters on the ROV to vector so as to produce thrust in the forward direction for that roller. Throttle movement to the rear likewise causes rearward thrust. Return of the throttle to its spring-loaded mid-point holds the thrusters in whatever position (and thus at whatever "horizontal" thrust) they have then reached.

20.7 The operator may choose to control motion and scraping from one half of the console and through the corresponding half of the ROV leaving the other half in the grip only and scraper raised condition until it is time to reverse the direction of working. It is mechanically advantageous to provide the drive for a scraper from its 'own' roller.

20.8 The console has the controls (not shown) for the hydraulic pump. These are an electrical start and stop switch and a hydraulic by-pass valve to control output pressure. A dial on the console shows the output pressure. The pump is driven by a totally enclosed induction motor of 45 kw drawing its supply from the platform or the ship at 415 volts, 3-phase and 50 or 60 hz.

20.9 The capstan winch, the A-frame and the umbilical drum are independent units which may be located up to 30 metres from the control cabin. They are readily mobile and are positioned on deck to suit the work site and the prevailing conditions. The capstan is driven by hydraulic pressure taken by independent 30 metre lines from the pump at the cabin. Controls are located on the capstan winch body.

20.10 The winch operator stands by the capstan and is in direct communication with the operator at the console by headphones and a microphone. The winch has rudimentary shelter. Dials on the capstan panel show the length of cable deployed and its tension.

20.11 The umbilical cable runs a maximum of 20 metres over the deck and into the umbilical holding drum which is located behind and beneath the capstan. From there it runs over the capstan and thence to the A-frame and to the ROV suspended on the end of the umbilical for deployment.

21.0 The ROV can be operated by one skilled and experienced man in the control cabin in addition to the winchman. Alternatively a two man cabin team can share the tasks between them. The skills needed are akin to those of a talented tractor-driver with a penchant for video-games rather than to those of a conventional submersible pilot.

22.0 Launch and Recovery of the ROV is a crucial phase of operations. It must take account of safety and other regulatory requirements of positioning and access on the platform or on the attendant vessel in relation to the ROV's work site as well as the state of wind, waves, current, tide, light and, on occasion, seabed.

22.1 The job calls for at least three men i.e. one in addition to the cabin operator and the winchman, and for four if assistance is given at cellar deck level with steadying lines to help position the ROV.

22.2 When the ROV is being launched from the platform on which it is to work the launching principle is to lower it down onto a submerged horizontal cross-member and start the thrusters when in position. The scrapers are lowered to act as buffers prior to start-up. The small size and considerable negative bouyancy of the ROV ensures that it sinks readily and is not thrown about by the sea. Recovery is the reverse of this process.

22.3 Some platforms e.g. the Conoco TLP, have ROV launch areas internal to the deck which give ready vertical access to horizontal cross-members. In such cases the job is straightforward as in 22.2 above. Things are seldom so simple but the compact size of Robby means that advantage can be taken of any small deck opening which is available.

22.4 Most platforms have a deck which is much wider than the support frame and do not have openings in the deck for ROV launch. Thus it is not normally possible simply to lower the ROV vertically from the deck onto the platform. In such cases launch is achieved by lowering the ROV from the edge of the deck in air to cellar deck level. There two men on the cellar deck attach running lines with which they pull the ROV inwards under the cellar deck so that when it is lowered further it lands on the horizontal frame.

22.5 For recovery the ROV makes its way to the outer surface of the platform directly beneath the winch and 5 to 10 metres below sea level. There it lowers both scrapers (brakes). The umbilical is winched quite tight and then the thrusters are turned off. The ROV swings outwards from the structure and is winched back up to the deck. Recovery is done during a time when the current is either slack or running away from the side of the platform with the winch.

22.6 Where the seabed is firm and unobstructed and visibility there is reasonable the ROV may be launched onto the seabed and from there driven over to a platform leg. (This is an instance where reduced hydraulic pressure and reduced thrust are employed). Then the ROV mounts the leg as described in 18.3 above. Recovery is either by returning to the seabed and winching from there or as in 22.5 above.

22.7 When the ROV is working from an attendant vessel the vessel is brought alongside the platform. From there the ROV is lowered onto the first horizontal frame and the launch process as in 22.4 above is carried out. Assistance may be given by men on the cellar deck. Recovery is as in 22.5 above with the ROV being winched onto the vessel.

22.8 If seabed conditions permit, launch and recovery from an attendent vessel to the platform may be via the seabed as in 22.6 above.

23.0 Rate of Work. For the embodiment here described this is based on the following parameters:

23.1.0 Width of cut, 0.4 metres; nett of overlap, 0.3 metres.

23.1.1 Angular sector cut, 90 degrees; nett of overlap, 72 degrees. Thus a pipe .48 m o/d or less needs 5 cutting runs to clean it.

23.1.2 A larger pipe needs circumference/0.3 runs to clean it. For example a 1 metre o/d pipe needs 11 runs to clean it.

23.1.3 The speed of Robby is 0.3 metres/second.

23.2 It is assumed that for each cutting run it makes Robby runs back light and spends time manoeuvring into position and that each of these occupies the same increment of time as does the cutting run. Therefore the apparent cutting speed is one third of the running speed. Standard practice is to do two cutting runs on each length of pipe. The first removes most of the growth and the second tidies up any remainder. Thus the effective working speed of Robby for full cleaning is 0.3/3/2=.05 m/s (180 metres/hour). Achieving that work rate during actual operating hours is taken as 100% efficiency.

23.3 In practice, additional time is taken up with working on nodes and anodes as well as in negotiating obstacles and moving from tubular to tubular etc. This means that the efficiency attained is always less than 100%. It is taken as 50% for average conditions with a good operator. Applying 50% efficiency to the 180 m/hour effective cutting speed in 23.2 above gives a nett cutting speed of 90 metres/hour.

23.4 A platform is analysed by diameters and lengths of all the structural members which need cleaning. The total length of cutting run needed is calculated as in 23.1 above.

23.5 For example on the platform described at 4.1 above (which is relatively large by southern North Sea standards) the total superficial area of tubulars to be cleaned is 2,995 sq metres and their total length is 2,044 metres. Most of these tubulars are .45 metres o/d or less and therefore need 5 runs each whatever their diameter. The total cutting run needed is 12,000 metres. The nett cutting speed is 90 metres/hour so the working time needed is 134 hours.

24.0 The foregoing deals only with the simplest version of the invention. Robby can readily be adapted to carry, say, a manipulator arm or a cathodic potential meter and to do other tasks. However, for "mussel bashing" duty such upgraded versions should not be used. The basic Robby should be retained for this work.

CLAIMS

1. That this invention can, while under remote control from a point above water, take a firm and stable grip upon, travel over and do work on the underwater surface of an offshore oil or gas production platform to a depth of at least 20 metres and do so on any member of the structure whatever be its nature, dimensions, angle or attitude.

2. That the cleaning device incorporated enables the invention, while under remote control from a point above water, to remove heavy marine growth of mussels, barnacles, kelp etc to the standard required to preserve the structural integrity of such a platform and to permit clear video inspection of its steel structure.

3. That the compact size and light weight inherent in the invention enable it to work as in 1. and 2.

above in sea areas where the current velocity on spring tides is up to 1 metre/second and where the forward visibility is as little as 2 metres.

4. That its compact size and light weight make it practicable to launch and deploy from a production platform without the need for an attendant support vessel.

5. That the simplicity and robustness of the invention enable it to withstand the very harsh environment created when hard marine growth such as mussels is cleaned and thus to operate reliably in this role.

6. That the said simplicity and robustness make the invention economic to build and to operate and ensure that if it is lost or damaged the loss is relatively small.

7. That no remotely-operated device presently exists which is capable of meeting the tasks and requirements of 1 to 6 inclusive above.

Amendments to the Claims have been filed, and have the following effect:—

(a) Claim 1 above has been deleted

(b) New claim 1 has been filed as follows:—

1. That the invention can, while under remote control from a point above water, take a firm grip upon, move along and around, negotiate protuberances on, inspect, clean and transfer between the submerged and interconnecting tubular members of an oil or gas production platform or like structure and do so on all tubular members from the largest down to those 0.1 metres in diameter.

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