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A Nonbuoyant ROV for Performing Heavy Subsea Work

by Per J. Thingstad and Haakon D. Hveding, *Myrens Verksted A/S*

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Abstract

A non-buoyant ROV for underwater use has been developed. It is heavy and powerful and is normally suspended in a wire from a crane. The operation of the ROV is from the deck and the control signals and power are fed through umbilical cable which is kept taut at all times. The ROV is equipped with 3 thrusters placed 120° apart and operating in the horizontal plane.
With the aid of a joystick, the operator can deflect the Spider with load, away from the vertical. The load and Spider may also be rotated. Working tools may be placed on this particular ROV.

This ROV has had operational experience since 1977, and on one unit more than 8000 hrs operation was logged within a few years. Other applications of these non-buoyant ROVs will also be looked into.

History

When oil was found in the Norwegian sector of the North Sea, it became natural for Norwegian industry to look for products for this new oil industry.

Myren, a mechanical workshop in Norway with about 320 employees and a member of the Kværner Group, the largest engineering group in Norway, was also interesting in getting involved in this new market. Realizing that diving would be a big market and that diving services are expensive and hazardous, it became obvious to Myren that tools to simplify the work on the bottom would be needed. These tools should preferably be operated from the surface. The idea was that these tools should take over simple and hazardous tasks in the first place and later on should be able to do more complicated work.
Thus the development of Myrens' Spider started in 1976.

Construction

The first aim behind the design and construction of Spider was to provide a vehicle with the ability to position heavy loads on the ocean floor without the need of divers or manual submersibles, or simply to pick up objects. This was to be done by remote control from the surface with the aid of video cameras, sonar and other navigation equipment and a tool package suited to the task at hand. Figure 1 shows a Spider.

The vehicle is suspended in a wire rope from a crane on the surface vessel, and its vertical position is controlled by the crane winch. The Spider shown is equipped with three thrusters acting in the horizontal plane. The thrusters are placed 120 deg. apart and the force vector produced from each thruster can be combined into a resulting force vector acting in any horizontal direction. The Spider will then move like a pendulum and the maximum radius will depend on available thrust and pendulum length. The thrusters may also produce symmetrical torque to rotate the Spider about its axis.
Underneath the Spider are shown special hydraulically operated claws for setting down concrete blocks on the ocean floor.

Design of the Spider

Hydraulic

In the early stages of the design much investigation was undertaken to determine in what way to power the unit. As for thrusters, very compact solutions can be obtained by using hydraulic motors driving a nozzle-type propeller. A higher efficiency may be obtained by using electric motors, but at the expense of size and neatness. Many schools of thought are involved in the electric/hydraulic discussion on sub sea propulsion; at Myren we tend to favour hydraulic drives for ratings less than, say, 5000 N per thruster. The Spider at present is equipped with thrusters giving 3500 N max. force.

One additional reason to favour a hydraulic drive system is the fact that tools and work equipment require hydraulic power in any case.

The hydraulic power could have been fed to the unit through hoses from the surface, but due to the prohibitive pressure loss at hose lengths of several hundred metres, the hydraulic pump is situated at the Spider and driven by an electric motor which in turn is fed with power through conductors in the umbilical cable.
Figure 2 shows a diagram of the hydraulic system. The main components are:

a) Electrohydraulic motor/pump. (1)
The electric motor and hydraulic pump is an integrated unit and mounted in a container filled with hydraulic fluid. This fluid circulates around the motor to conduct the heat away from the motor and out to the hydraulic pipes, etc. which are cooled by the ambient seawater.

The pump is of the axial piston swashplate type, fitted with a pressure regulator. Thus the pump displacement is varied to keep the system pressure constant.

b) Manifolds and valve system. (4)
Electrohydraulic servo- and on/off valves are used to control the thrusters and auxiliary functions. Some of the valves are connected to quick-disconnect couplings, and can be used to drive various interchangeable tools as required by a particular task.

c) Hydraulic thrusters. (6)
These consist of a hydraulic axial piston, fixed displacement motor connected directly to the propeller. The pitch of the propeller may be set to optimize the oilflow/differential pressure for a given situation. The thrust is controlled by varying the oilflow to the motors by the servo valves.

d) Pressure compensator. (5)
The hydraulic system must be able to run at varying depths, and must be well sealed to prevent ingress of seawater. Variations in oil volume due to temperature and variable volume tools must be catered to. The pressure compensator is in principle a rubber bellows which is subject to the ambient seawater pressure plus an additional pressure. The additional pressure ensures that the oil is always at a higher pressure than the seawater such that any small leakage will result in oil loss instead of water ingress.

The additional pressure is provided by a hydraulic piston that is connected to the main pressure line of the system. The area ratio of the piston to the bellows gives the overpressure with respect to the ambient.
An additional spring-type compensator may be mounted to ensure a positive overpressure in case the main pressure is absent.

e) Hydraulic converter
Many of the auxiliary functions may be performed by exposed tools that may be easily torn off or are subject to leakage. Therefore, some of the functions are powered by a secondary system separated from the main system by a converter. This consists of a hydraulic motor driving a pump. The two hydraulic systems (main and secondary) are quite separate. The secondary system is pressure compensated by a rubber membrane only.

Electronics & Control System

The exchange of information between the subsea Spider and the operator at the surface requires some remote control system. The electronics on the earliest Spider was fairly simple, using two coaxial cables for telemetry and remote control and another coaxial cable for video transmission. A more effective system uses two coaxial cables for telemetry, two simultanous videosignals, a sonar system and additional acoustic systems. In fact, the two control systems developed for Myrens buoyant ROVs may easily be adapted and expanded to virtually any size required.

Figure 3 shows the operator's panel. An X-Y type joystick controls the pendulum motion of the Spider. A separate control rotates the unit around its axis. The Spider is stablized against unwanted rotation by a rate-gyro or by a gyrocompass if such is in use. The panel also has controls for camera and lights. Controls for tools, etc. are easily fitted due to the modular construction of the console.

Fig. 4 shows the cable winch container. This particular winch can take 350 metres of cable. The winch is driven hydraulically and the tension is adjusted such that the umbilical cable is held taut between the winch and the Spider. The umbilical cable is reinforced with kevlar fibres and has a breaking load of about 30 tons. Thus the umbilical cable may be used for emergency recovery, should the suspension wire break. The winch also has a spooling gear.

The cable has three power conductors, three coaxial cables and four conductors for auxiliary power.
A protective ground screen covers all the conductors. Figure 5 shows a cross section of this umbilical.

Umbilical termination has been done in various ways. The earliest designs relied on epoxy moldings to terminate the strength members of the cable. However the molding technique requires quite a long time for curing, and to permit a retermination in only 2-3 hours, the design had to be changed.
Later designs rely on gasket seals, and the termination space is filled with oil and pressure-compensated.

TECHNICAL SPECIFICATIONS

The specifications below are for the Spiders built so far. The Spiders are, however, built up of modules, and power requirements, etc. may easily be altered according to need:

Submersible Vehicle:

Diameter:	2,3 m approx.
Height:	2 m approx.
Weight in air:	3,5 tons approx.
Propulsion:	3 thrusters mounted in a 120^{o} array around the vehicle, each giving a bollard push/pull of approx. 3500 N providing a 6500 N force in any direction.
Propulsion power rating of vehicle:	80 HP (electrical input at 440 V, 60 Hz)
Propulsion control:	Electrohydraulic servovalves
Rotation stability:	Rategyro or gyrocompass
Hydraulic functions:	Additional valves and system according to requirements.

Fig. 6 shows the horizontal moving capability of the Spider as a function of Spider weight with load, and distance from point of suspension.

Umbilical:

Length:	250 m (or more if required)
Diameter:	47 mm
Weight in air:	2,47 kg per m
Weight in water:	0,72 kg per m
Breaking strength:	30 tons (calculated)
Stress members:	Braided Phillystran fibres
Power transmission:	60 KW at 440 V on 3 x 26 sq. mm conductors (Cu), auxiliary power on 4 x 2,5 sq.mm. conductors plus 18 sq. mm. ground conductor.
Signal transmission:	3 coaxial calbes (RG-59)
Umbilical termination:	Phillystran mechanical, epoxy mold (Myren design).
Electrical:	Two stage gasket seals, including individually sealed conductors.

Umbilical Handling System:

The system is mounted in an 8 ft. x 14 ft. container. Motor starters, current, voltage, and frequency instruments. Rotary h.f. joint and slip ring assembly for umbilical. Constant tension, hydraulically operated drum for umbilical cable.

Electronics:

The operator console is mounted in an 8 ft. x 10 ft. container.

Multiplex system:	Pulse code modulation.
Bit rate:	200 k/bit per sec. 2 coaxial cables.
Circuitry:	CMOS, LSI. Double Euro size circuit boards.
Format:	Frame of 32 words, 8 bit each.
Control inputs:	Joystick and push-button.
Displays:	Heading, video-monitor, control lamps, continuous monitoring of hydraulic parameters, etc.

Instruments:

2 pan and tilt vidicon TV cameras (one signal monitored at a time), 1 video tape recorder, 3 x 250 W light projectors, 1 gyrocompass, depth and height gauges.

OPERATIONAL EXPERIENCE

The first job for the Spider was successfully performed in the British sector of the North Sea in the fall of 1977. A loading buoy had been subjected to under-pressure by accident, and the oil company and authorities were afraid the buoy might become deformed below water level.

Two diving teams in the area were asked to check the buoy for deformations, but they had no method of doing so. Myren, hearing about the accident, proposed a way of discovering any deformations which was accepted.

The proposed solution consisted of fastening a beam bent to the same radius as the buoy to a Spider. The Spider with the beam was suspended from a crane onboard the loading buoy (see figure 7). From the amount of cable payed out, one would know the depth of the Spider. The thrusters on the Spider were used to force the Spider up against the buoy, supporting the Spider on three points. The thrusters had no problem in keeping the Spider in a stable position.

A level was placed on the beam to make sure it was horizontal. Rows of anodes fastened on the buoy were used for positioning the beam horizontally.

Onto the beam, a cart was fastened which would travel along the beam. On the cart was a hydraulically driven plunger to push it up against the wall of the buoy. One tape measure was fastened along the beam, and one was fastened to measure the position of the plunger.

Figure 8 shows the beam fastened to the Spider. One can see the cart and the TV camera fastened on the top of it. This TV camera was used to read the position of the cart along the beam and the position of the plunger. The camera on the pan & tilt unit was used to get an overall view of the working situation. Figure 9 shows the Spider on the way off the platform and down to the water.

When the Spider had arrived at the desired position, the cart, starting at one end, would measure the distance between the beam and the wall. The cart was moved a required distance along the beam and a new distance to the wall was read.

The Spider was moved around the buoy to check all the desired positions, and some 3000 measurements were made.

There were some doubts regarding the reliability of the measurements, so before the job was terminated Spider was taken back to the starting point to read some of the orginal measurements. The new measurements deviated less than 5 mm from the orginal measurements. The operation took about one week to complete.

A Spider was sold to Stolt-Nielsen in Norway in 1979. It was used as part of a system to bury the gas trunk-line from Ekofisk to Emden, across Danish territory, with gravel. Figure 10 shows a picture of the total system.

The ship, a 22 000-ton converted bulk carrier, carried gravel from shore to the field where the pipes were to be covered. From a moon pool in the center of the ship, the Spider was lowered with a drop pipe attached to it. This drop pipe was fed with gravel via conveyors and a hopper from the ship's hold. The Spider was used to move the drop pipe to the desired position. The gravel could then be discharged very efficiently for burying the pipe. Instruments fastened to the bottom of the Spider on hydraulically operated arms were used to check that the cover over the pipeline was adequate.

Figure 11 shows the Spider used for this particular job. The drop pipe for the gravel passes through the center of the Spider with the components placed around the drop pipe. More than 8000 operating hours have been logged on this Spider.

Figure 12 shows a Spider equipped with a special frame for cleaning and inspecting concrete structures. Both brushes and water jets were used for removing growth. A high pressure pump (200 bar) was placed on the Spider for jetting purposes.

The Spider was lowered from a special cart travelling on beams underneath the deck of the concrete platform. The thrusters were used to push the frame up against the wall to be cleaned and inspected. A water jet, brush, video camera, and still cameras were placed on a cart mounted on the frame. Once the Spider was in place, pushing the frame up against the structure, the cart was moved sideways and up and down for cleaning and inspecting the area of the frame. The cart could also move in and out from the wall such that the distance could be optimized during cleaning, and so that the still camera could take pictures that were in focus afterwards.

The system works quite well. Brushing goes faster than water jetting, but water jetting gives a cleaner surface.

OTHER POSSIBLE APPLICATIONS OF THE SPIDER

Orginally, the Spider was intended to be used for positioning objects accurately on the ocean floor by remote control, or for picking them up by means of manipulatorarms placed under the Spider.

As our operating experience shows, the Spider has actually been used for entirely different applications, and another possibilities are limited only by one's imagination.

Let us look at two additional possible applications for a Spider:

1. Underneath any platform, there is a need to carry out inspection, maintenance work, etc. Today, this is mainly done from a vessel moving up to the platform, and divers or ROV's operating from the vessel.

   Such vessels are expensive, and can operate close to the platforms only when the weather is good.

   If the platform deck was equipped with I-beams underneath, the work could be deployed from the platforms along the I-beams. These I-beams could be used to deploy divers, ROV's in general or a non-buoyant ROV in particular.

   The Spider might work by itself doing cleaning, inspection, manipulative work, and perhaps retrieval of dropped items. It could, however, also assist divers in replacing items like anodes, and divers might for instance use power from the Spider for operating hand tools etc. The advantages of using a Spider over existing methods are:

   - It is heavy, and therefore little influenced by the weather.
   - It can operate more easily in the splash zone
   - In case of power failure, it will hang straight down, and may be winched straight up to the I-beam.

2. A specially equipped Spider-type vehicle could be used for servicing subsea completion systems. It could be deployed from a ship, possibly using a heave compensator, and land on a rail system provided on the subsea completion unit. Once it had landed, the wire lifting the Spider could be slacked off so that the Spider would be independent of the supply vessel's movements.

   Special tools could be fittet onto the Spider (see for example Fig. 12) for replacing valves, etc. However, here it is important that the Spider with tools and the subsea installation be custom-made for each other.

   General manipulators could be used for simple, general purpose work.

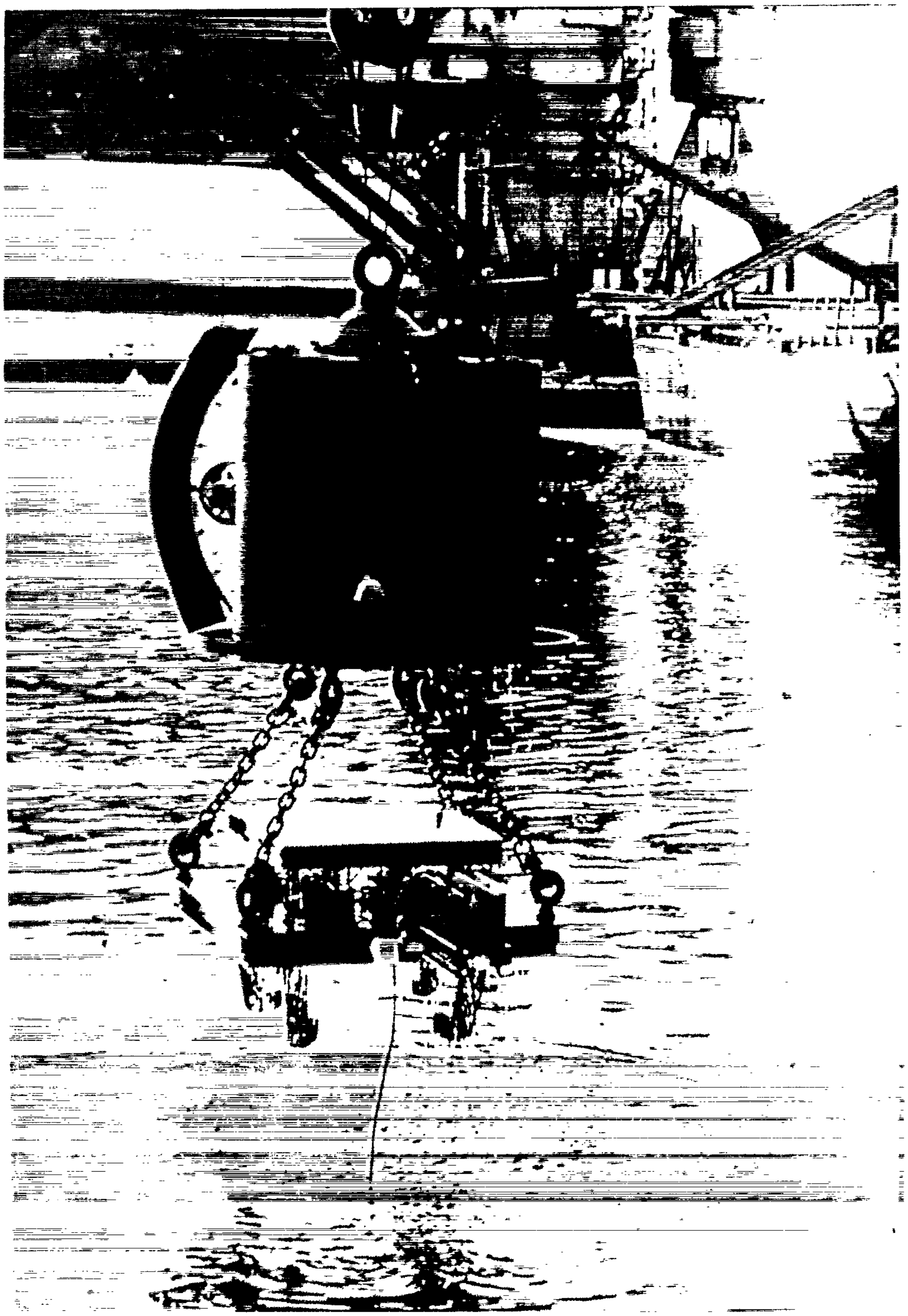

Fig. 1 — Spider with lifting stool for saddle blocks

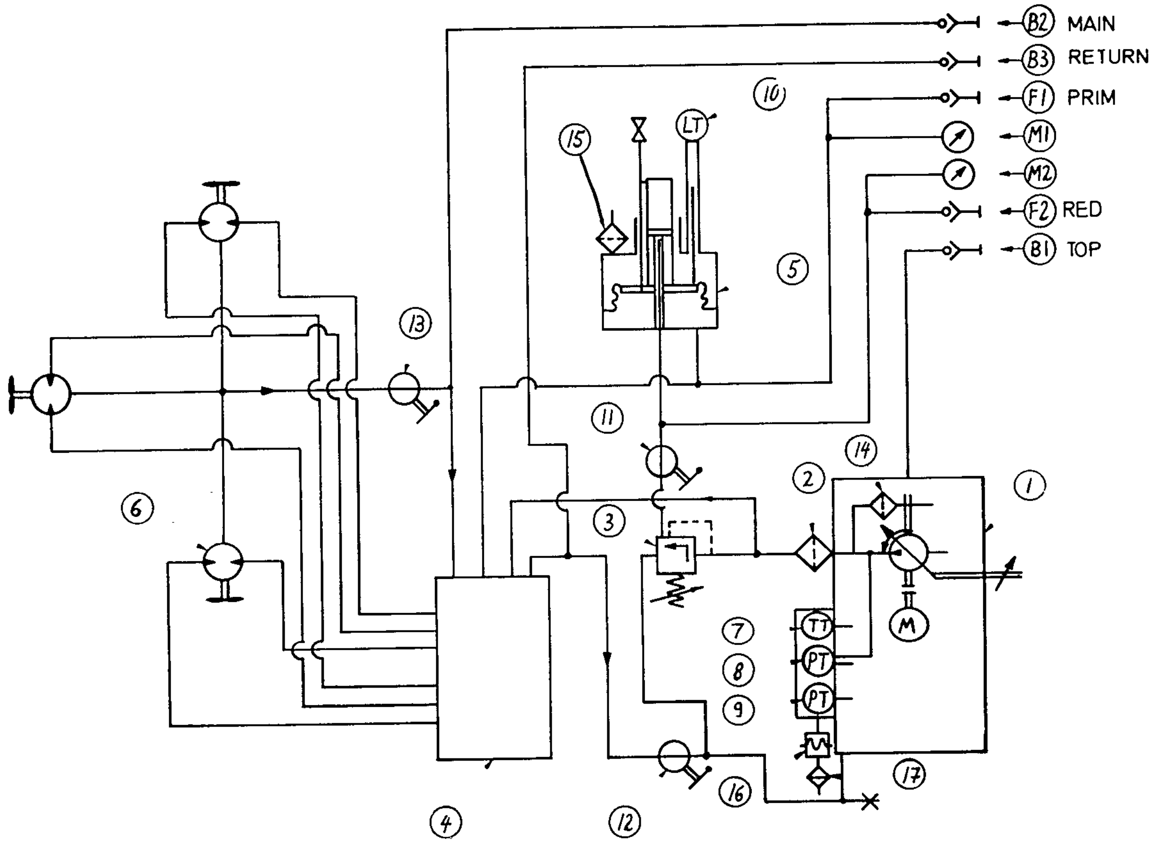

Fig. 2 — Hydraulic diagram for Spider

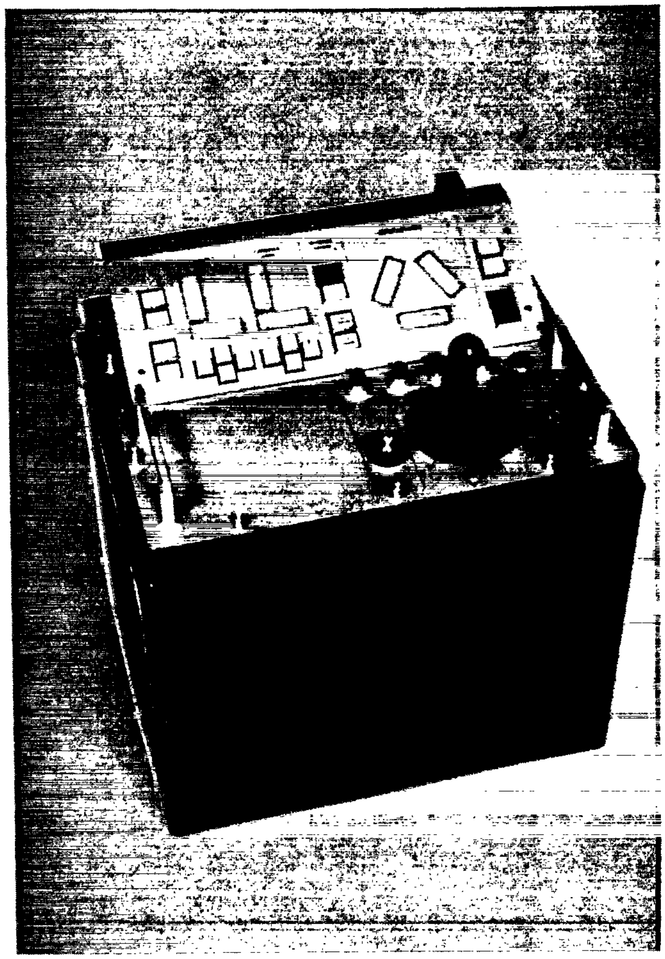

Fig. 3 — Spider operators control panel

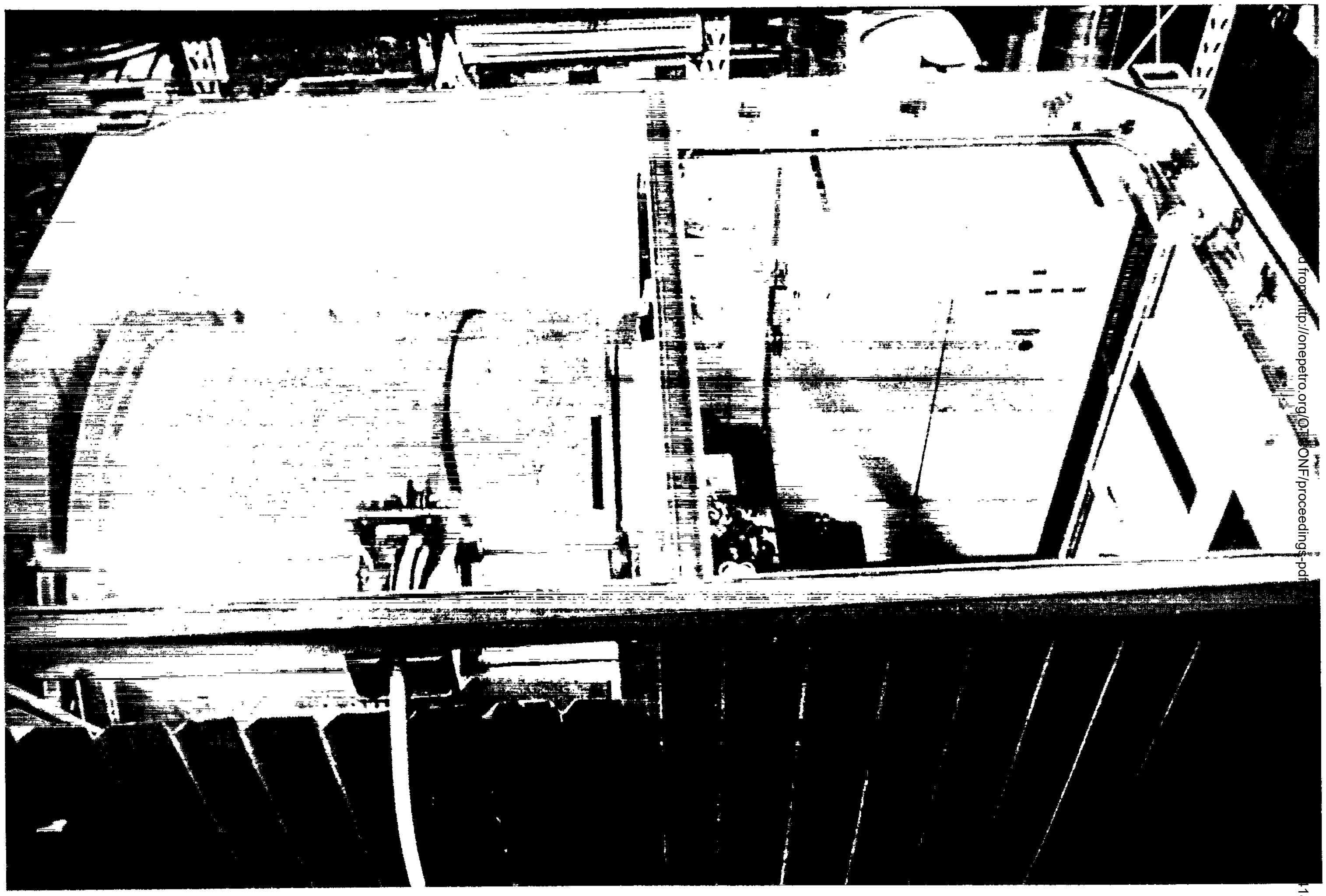

Fig. 4 — Cable winch container

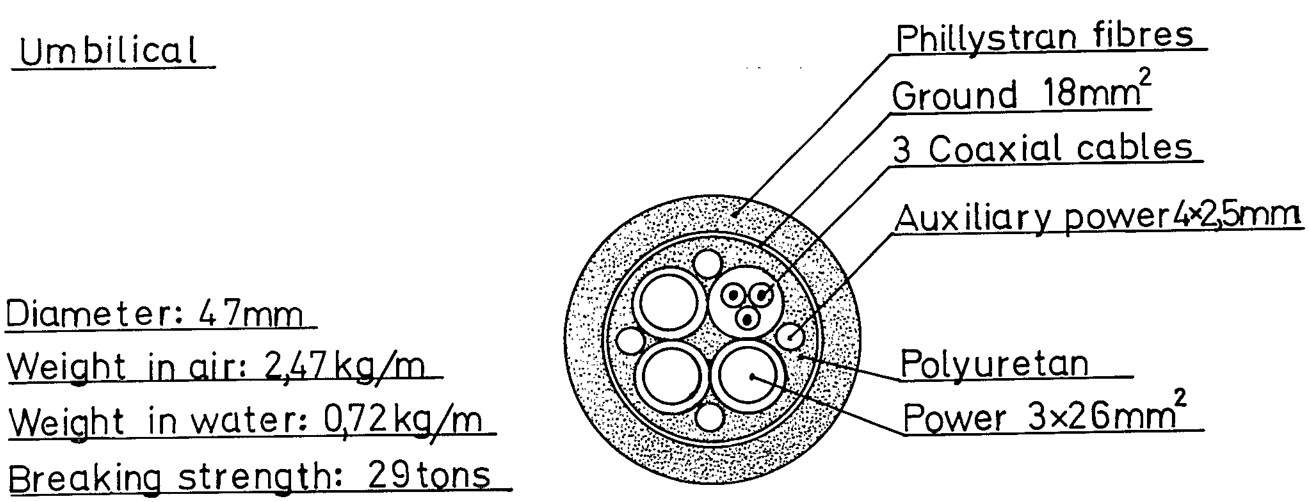

Fig. 5 — Umbilical crossection

S P I D E R   F O O T P R I N T

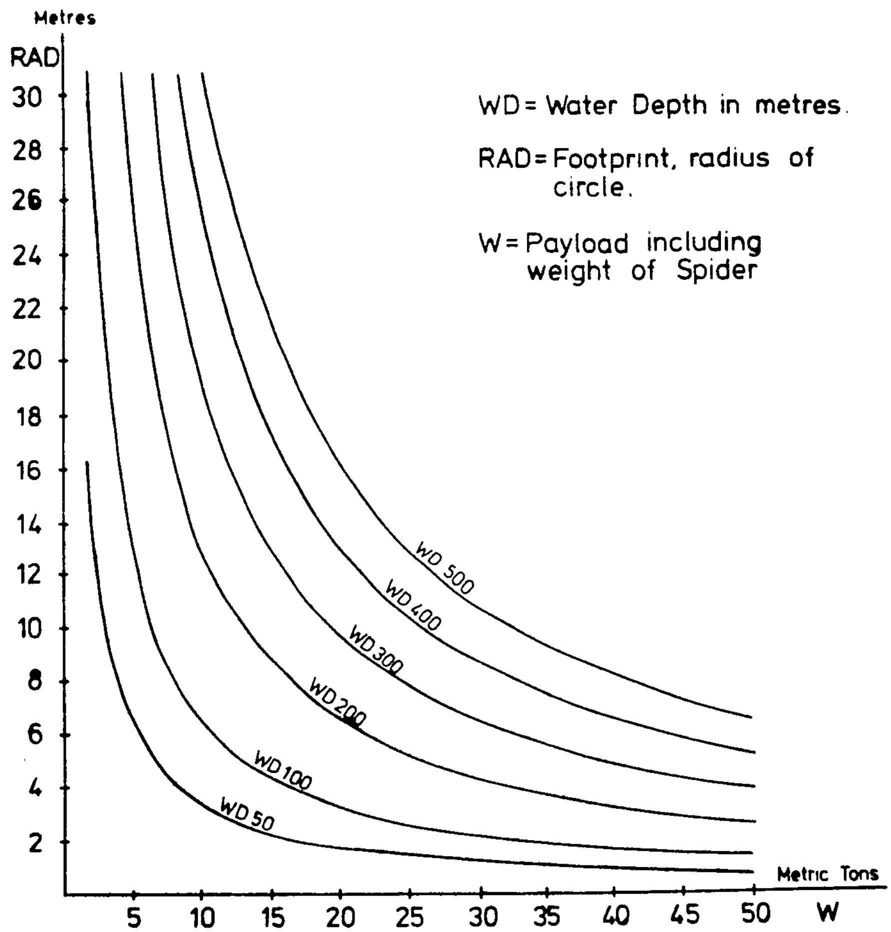

Fig. 6 — Spider footprint

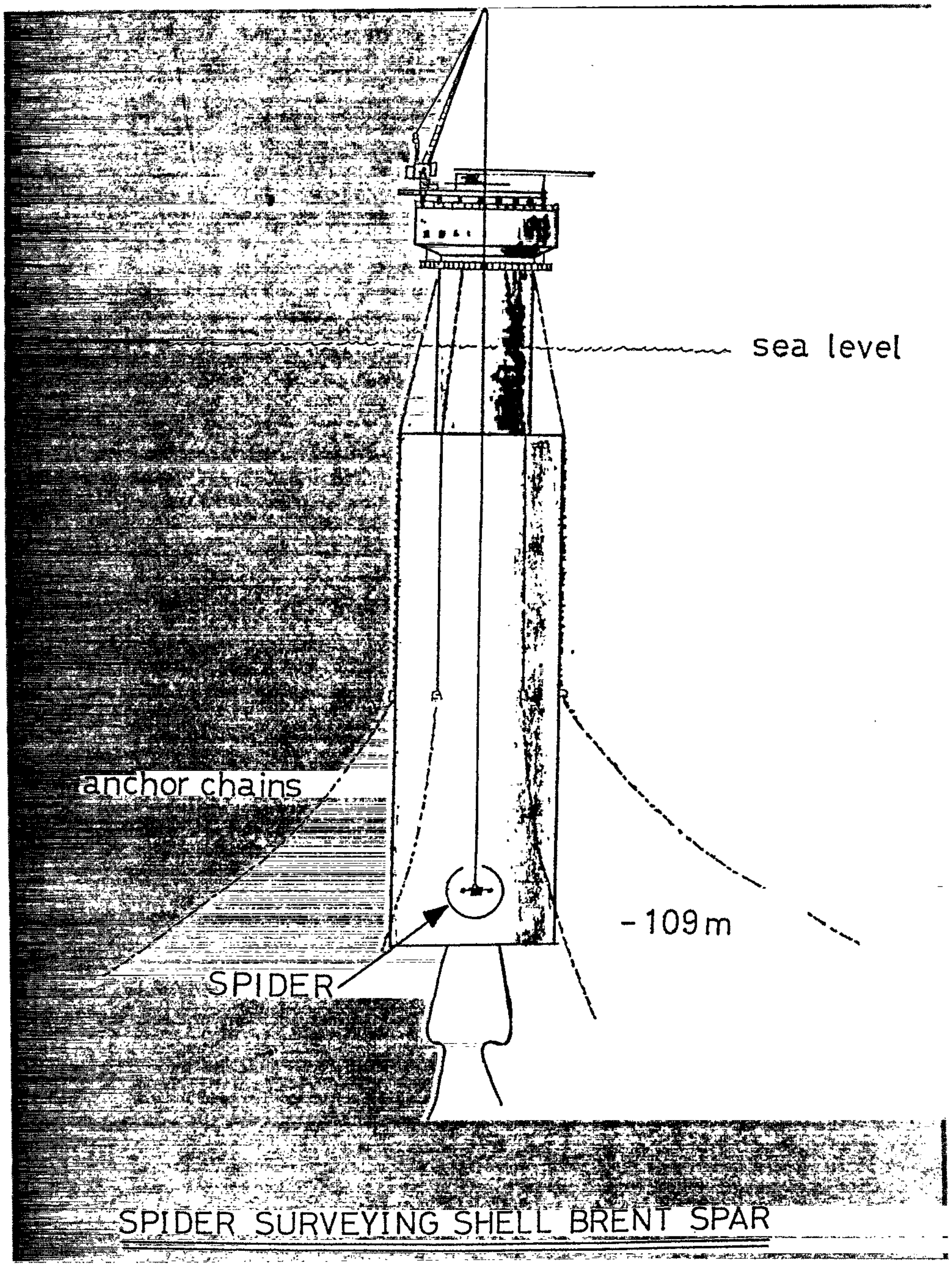

Fig. 7 — Spider working on a loading buoy

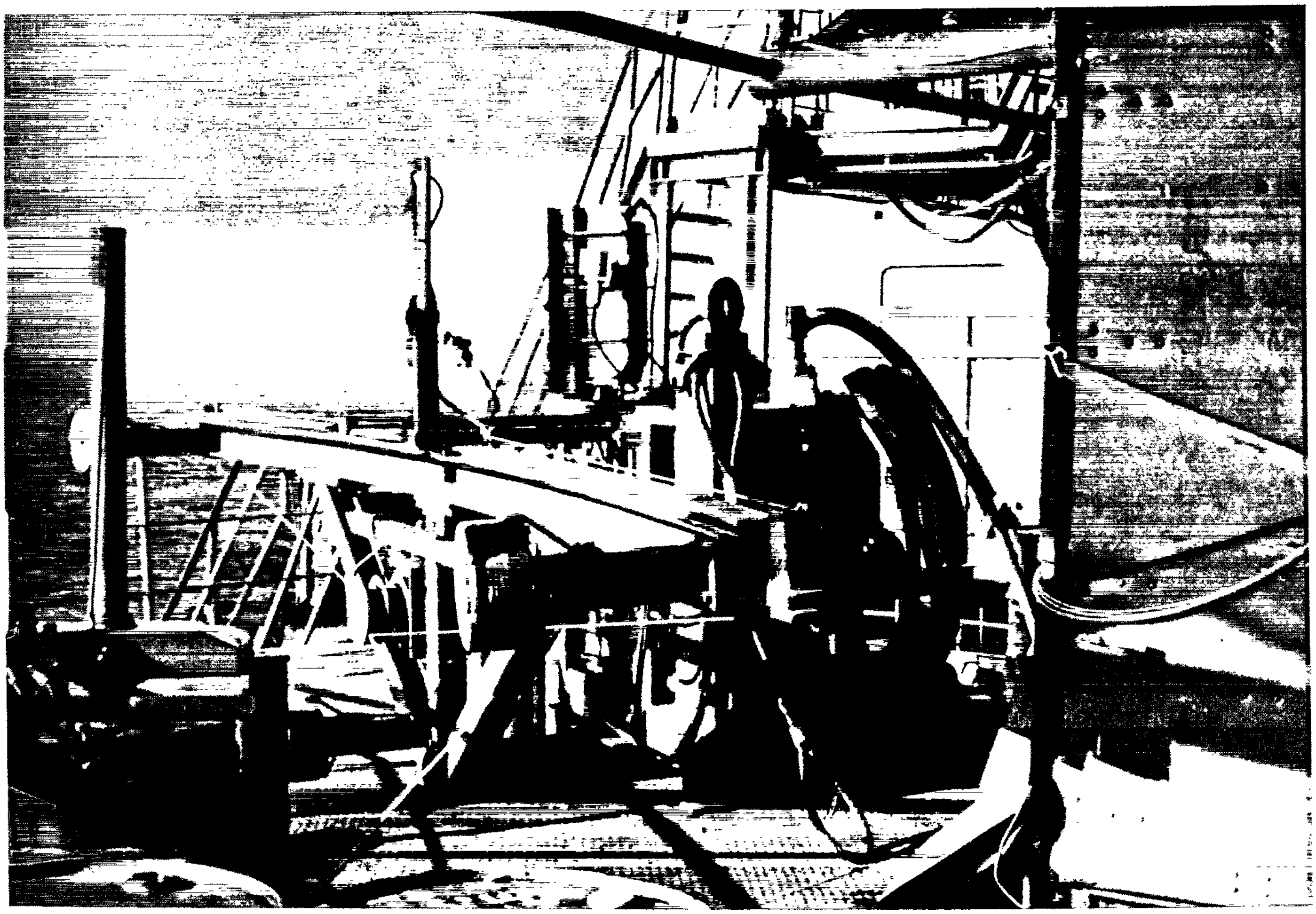

Fig. 8 — Spider with measurement tool

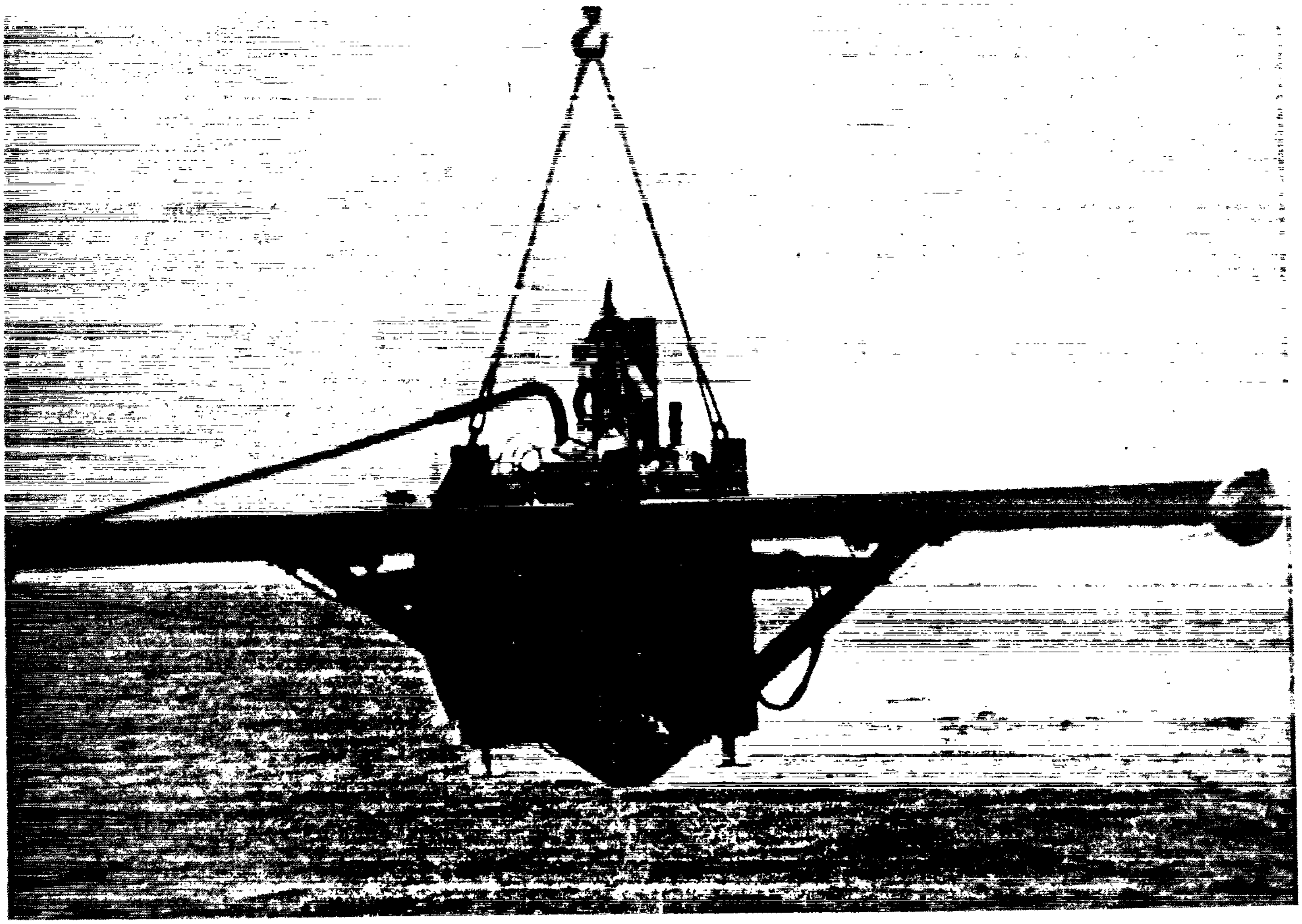

Fig. 9 — Spider being deployed

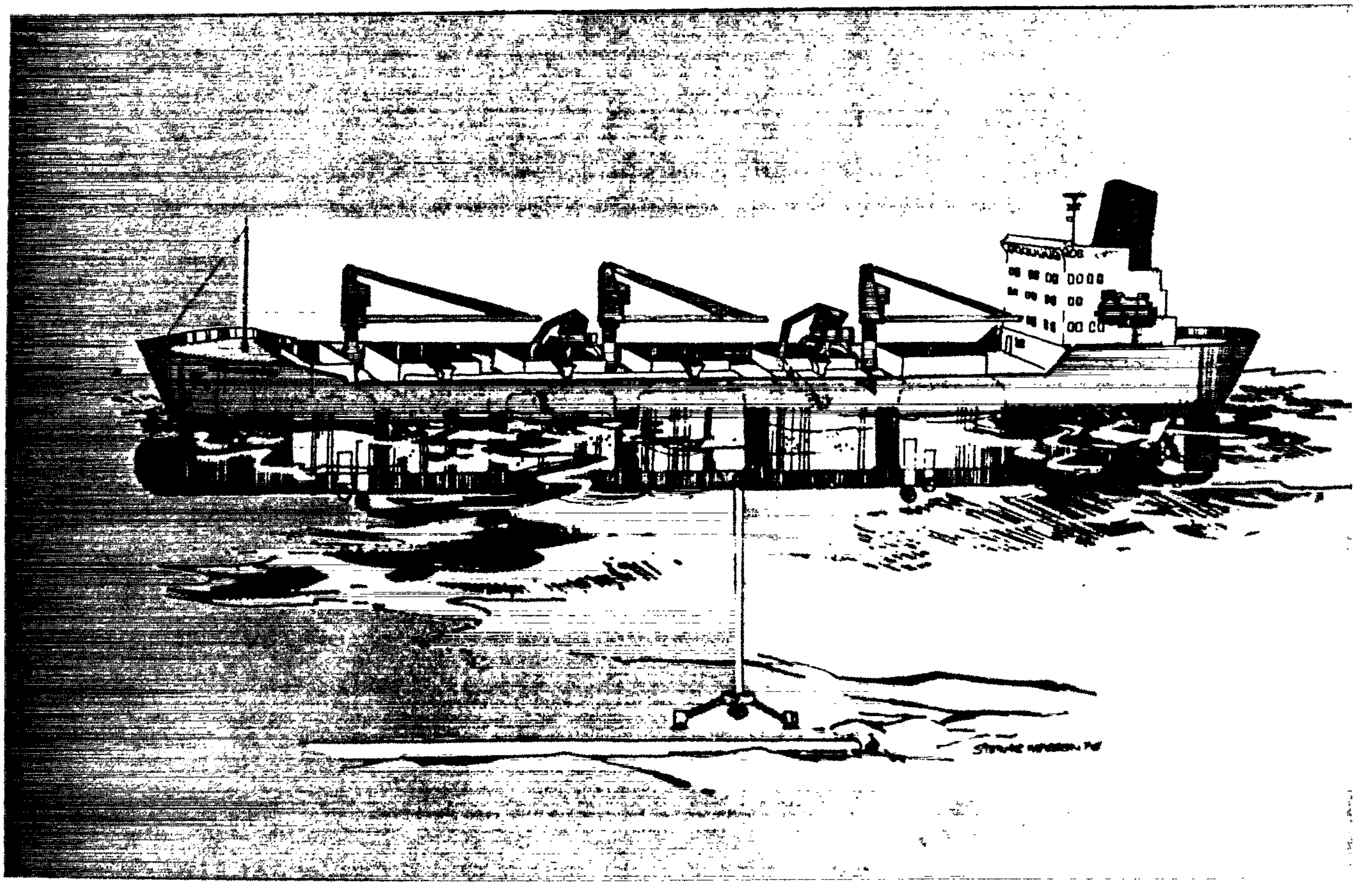

Fig. 10 — Precision gravel dumping system

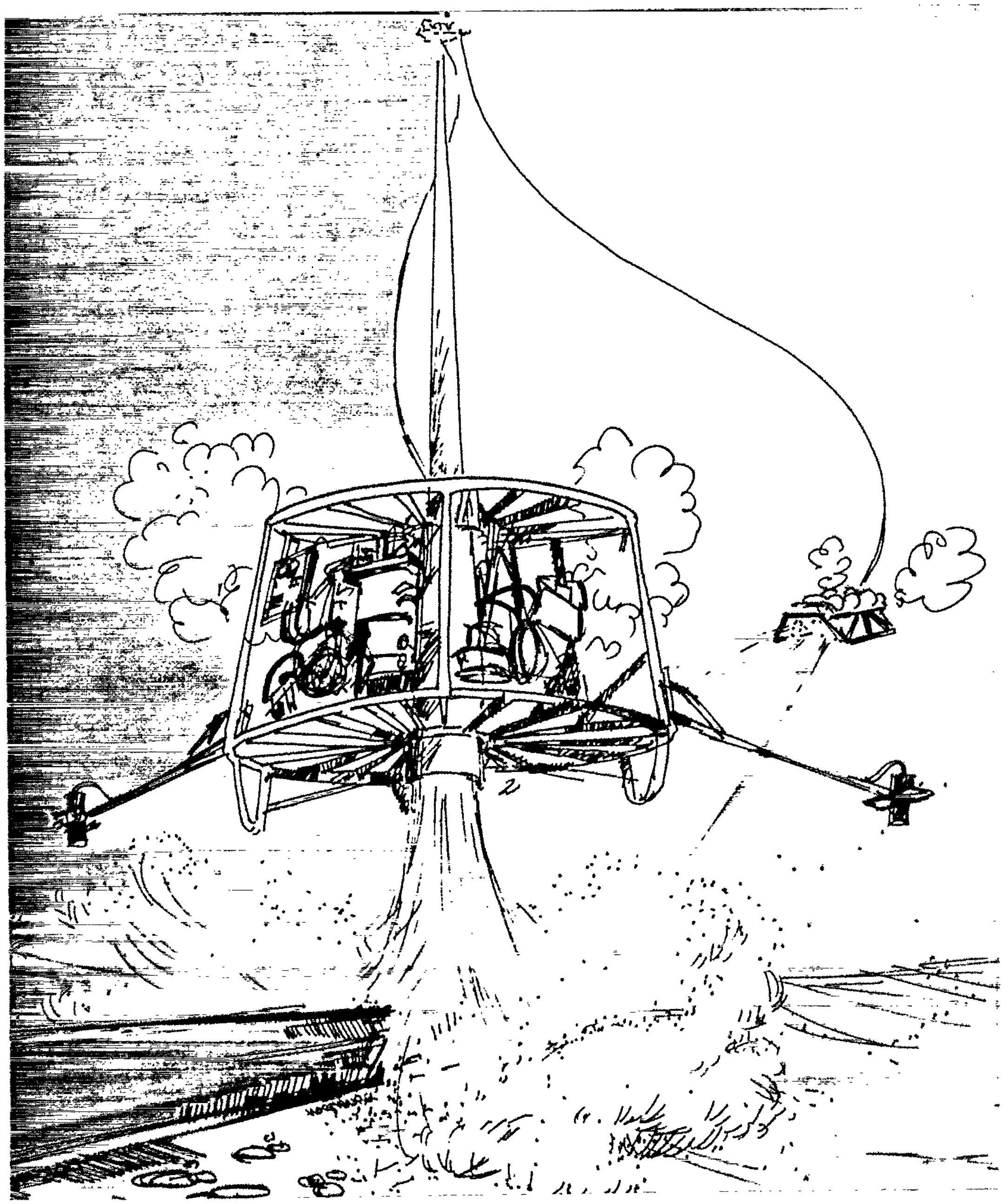

Fig. 11 — Spider steering of gravel drop line

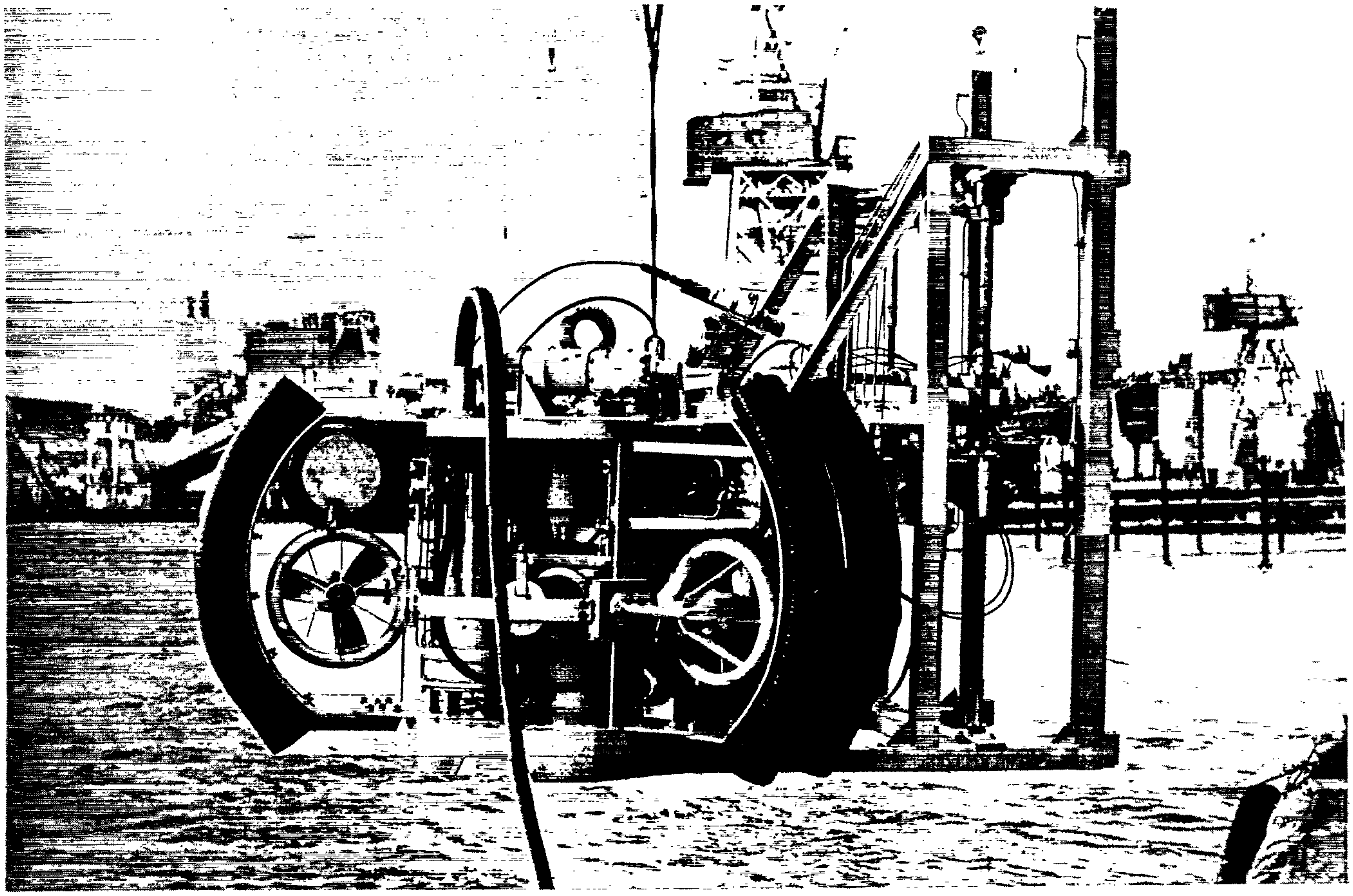

Fig. 12 — Tool frame for cleaning and inspection fitted on Spider