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Design and Development of a Hydraulic Powerpack-Driven Boom Reel System for Oil Spill Containment Applications

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Abstract: Oil spill incidents create serious risks for marine ecosystems, coastal infrastructure, industrial operations, and environmental safety. In emergency oil spill response, containment booms must be deployed and retrieved quickly to restrict the spread of floating oil. Manual boom handling is slow, unsafe, and difficult, especially when the boom becomes waterlogged or exposed to wave and current action. This paper presents the design and development of a hydraulic powerpack-driven boom reel system for oil spill containment applications. The proposed system is intended to handle a 3.5-ton operational load, operate at a controlled reel speed close to 7 RPM, and support high-torque boom retrieval under industrial working conditions. The system consists of a heavy-duty boom reel frame, rotating drum, support structure, shaft, bearings, hydraulic motor, gearbox, diesel engine-driven hydraulic powerpack, flow control valve, pressure control elements, filtration unit, and safety components. The design was developed using mechanical design principles, 3D modelling, frame design, hydraulic circuit planning, and preliminary Fusion 360 structural simulation. The hydraulic drive calculation was performed for an OMSU 200 hydraulic motor, 15 LPM available flow, 215 bar pressure, and 6.1:1 gearbox reduction. The calculation showed an estimated motor torque of 122 Nm at 15 LPM, output speed of 12.17 RPM with one gearbox, and 6.14 RPM when the flow is divided between two gear motors. The calculated gearbox output torque was approximately 744.2 Nm, indicating that further drivetrain optimization is required to fully satisfy the 2700 Nm target torque. The preliminary cost estimation of the boom reel was found to be approximately ₹1,80,000 to ₹2,50,000. The study demonstrates that a hydraulic powerpack-driven boom reel can reduce manual effort, improve operational safety, ensure controlled boom handling, and provide a practical foundation for industrial oil spill response equipment.

Keywords: *Boom reel, hydraulic powerpack, oil spill containment, hydraulic motor, marine emergency response, structural design, Fusion 360 simulation, torque transmission.*

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I.INTRODUCTION:

Marine oil spills are among the most harmful environmental accidents because they directly affect seawater quality, marine organisms, coastal activities, fisheries, ports, and industrial facilities. During such incidents, the immediate control of floating oil is essential. Oil containment booms are widely used for this purpose. They act as floating barriers that restrict the horizontal spread of oil and guide it toward recovery systems such as skimmers.

However, the effectiveness of oil spill control depends not only on the boom material but also on how quickly and safely the boom can be deployed and retrieved. Long containment booms are heavy and difficult to handle manually. Their weight increases further after contact with water, oil, dirt, and marine debris. Manual handling also creates safety risks for operators, particularly during emergency response, rough weather, or offshore operations.

A boom reel is a mechanical system used for storing, winding, deploying, and retrieving long lengths of containment boom, hose, cable, or similar flexible equipment. In marine oil spill applications, the boom reel must provide smooth winding, uniform retrieval, sufficient torque, stable structural support, and reliable operation under harsh environmental conditions. For heavy-duty oil spill response, hydraulic actuation is suitable because hydraulic systems provide high torque, smooth control, compact power transmission, and reliable operation in rugged environments.

The present work focuses on the design and development of a hydraulic powerpack-driven boom reel for oil spill containment applications. The project was developed under an industry-institute context with Meenita Innotech Pvt. Ltd. in collaboration with Truetech Vision Pvt. Ltd. The major design requirement was to develop a heavy-duty boom reel capable of handling a 3.5-ton load, supporting controlled rotation near 7 RPM, and addressing a target torque requirement of 2700 Nm for safe boom retrieval.

II. PROBLEM STATEMENT

Oil spill incidents in marine and coastal regions require fast deployment and controlled retrieval of long containment booms. Conventional manual boom reel systems have several limitations, including high manpower requirement, slow operation, poor speed control, difficulty in rough weather, increased operator fatigue, uneven winding, and safety hazards during emergency response.

Therefore, the problem addressed in this study is to design and develop a heavy-duty oil recovery boom reel system with hydraulic powerpack support for controlled boom deployment and retrieval. The required system should be structurally stable, mechanically reliable, suitable for industrial fabrication, and capable of operating under practical marine emergency conditions. The design target includes 3.5-ton load handling capacity, 2700 Nm target torque output, and approximately 7 RPM controlled operating speed.

III.LITRATURE REVIEW

Oil spill containment systems have been studied through experimental, analytical, and numerical approaches. Muttin et al. studied numerical modelling and experimental behaviour of oil-spill curtain booms and showed that boom performance depends strongly on hydrodynamic conditions, boom shape, and deployment conditions [3]. Brown, Goodman, and An investigated containment booms in fast-flowing water and highlighted that conventional boom systems may fail when exposed to high current velocity and unstable flow conditions [5]. Muttin and Nouchi applied finite-element methods to study boom behaviour under wave and current loading, which is useful for identifying operational limits and improving structural design [6].

Yang and Liu used SPH-based numerical modelling to study oil containment boom performance and reported that boom failure may occur due to heavy oil, higher boom velocity, wave action, and unsuitable skirt angle [10]. Borri, Lugni, Greco, and Faltinsen experimentally studied water-oil-boom interaction and failure events, showing that improved prediction tools are needed to evaluate boom behaviour under practical environmental conditions [11]. Fang and Wong proposed an advanced Volume-of-Fluid algorithm for oil boom design and showed that fluid interface modelling can support the design of improved oil containment systems [12].

Along with hydrodynamic performance, mechanical reliability is also important in boom reel design. Fard et al. discussed fatigue analysis of rotating shafts subjected to combined loads, which is relevant for boom reel shaft and bearing surfaces subjected to repeated deployment and retrieval cycles [1]. ISO 4301 provides classification guidelines for crane-type equipment and duty cycles, which can support the selection of suitable structural members and load-bearing components [4]. SFS-EN 2768-m and EN ISO 13920 provide tolerance guidelines for general and welded structures, which are useful for ensuring dimensional accuracy and weld quality in fabricated boom reel frames [8], [9]. Internal marine equipment design practices also emphasize continuous welding, corrosion resistance, and closed-structure protection to avoid crevice corrosion in marine environments [2].

From the reviewed literature, it is clear that oil spill boom systems require both hydrodynamic reliability and strong mechanical handling equipment. Many studies focus on boom behaviour in water, but practical mechanical systems for boom storage, deployment, retrieval, and hydraulic actuation also require detailed design attention. The present work addresses this gap by developing a hydraulic powerpack-driven boom reel system with structural frame design, hydraulic circuit planning, simulation, torque calculation, and cost estimation.

IV.OBJECTIVE OF THE STUDY

The main objectives of this work are:

1. To study the functional and operational requirements of an oil spill containment boom reel system.
2. To design a heavy-duty boom reel structure suitable for industrial and marine emergency applications.
3. To develop a hydraulic powerpack-based drive system for controlled boom deployment and retrieval.
4. To prepare CAD-based frame and assembly models for fabrication planning.
5. To perform preliminary structural simulation using Fusion 360.
6. To calculate motor torque, reel speed, gearbox output, and drivetrain performance.
7. To estimate the preliminary project cost of the boom reel and hydraulic powerpack system.
8. System Design and Methodology

System Design and Methodology

5.1 Boom Reel Design

The boom reel is designed as a heavy-duty rotating drum system supported by a welded frame. The major components include the drum, shaft, side flanges, base frame, welded support frame, bearing units, gear mounting arrangement, and boom guiding system. The drum stores and retrieves the containment boom. The side flanges prevent the boom from slipping during winding. The shaft transfers torque from the drive system to the drum. Pillow block bearings support smooth rotation and reduce friction.

The orthographic views of the design include front, top, and side views. These views define the drum diameter, total width, support height, internal clearance, reinforcement position, and load transfer path. The frame is designed with structural members and bracings to resist bending, vibration, torsion, and dynamic loading during reel operation.

Figure 1. Orthographic design views of boom reel assembly

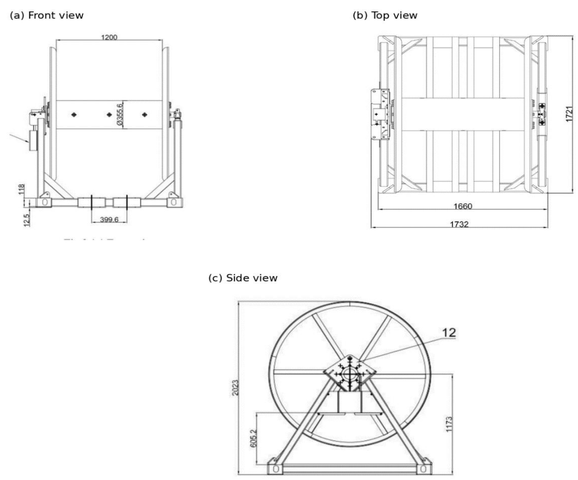

Figure 1. Orthographic design views of the proposed boom reel assembly showing front, top, and side views.

Base Frame Design

The base frame acts as the foundation of the boom reel system. It supports the reel drum, shaft, bearing housing, motor mounting, and other related components. The base frame must resist static load, dynamic load, torque reaction, vibration, and impact force. Important design considerations include load capacity, structural stiffness, centre of gravity, mounting accuracy, material thickness, ease of fabrication, corrosion protection, and maintenance access.

The frame design uses standard steel sections and plate members to simplify manufacturing. Square tube sections of 100 × 100 × 5 mm and PL4 plates are considered for the structure. Triangular bracings and cross members are used to improve rigidity and distribute load uniformly.

Welded Frame Design

The welded frame is designed as a rigid structure with horizontal, vertical, and inclined members. Welded joints are planned to provide sufficient strength at critical load transfer points. The design also considers weld accessibility, joint preparation, fabrication sequence, and inspection. Since the system may operate in marine or coastal environments, surface treatment and corrosion protection are important. Primer, industrial anti-corrosion paint, and marine-grade coating are recommended to improve service life.

Hydraulic Powerpack Design

The hydraulic powerpack provides pressurized hydraulic oil to drive the hydraulic motor connected to the boom reel drum. The system includes a diesel engine, hydraulic pump, hydraulic tank, suction strainer, pressure line, flow control valve, directional control valve, hydraulic motor, oil cooler, return filter, pressure indicator, temperature gauge, low oil switch, high temperature switch, hoses, and safety valves.

The diesel engine acts as the prime mover and drives the hydraulic pump. The pump draws oil from the tank and sends pressurized oil to the control valve. The flow control valve regulates the oil flow to control reel speed. The directional valve controls forward and reverse rotation of the reel. After passing through the hydraulic motor, oil returns to the tank through the cooler and filter. The relief valve protects the system from overload conditions.

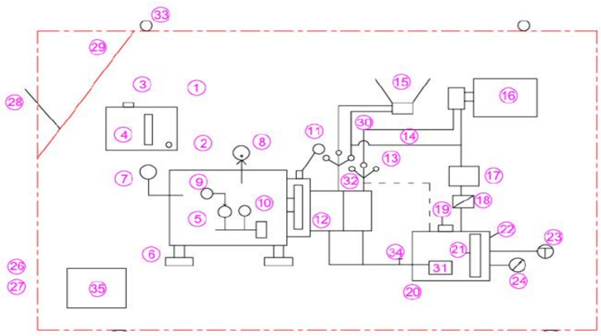

Figure 2. Hydraulic powerpack circuit diagram used for controlled operation of the boom reel system.

Working Principle

The working principle of the hydraulic boom reel is based on fluid power transmission. When the diesel engine starts, it drives the hydraulic pump. The pump draws oil from the reservoir and pressurizes it. The pressurized oil flows through control valves and reaches the hydraulic motor. The motor converts hydraulic energy into rotary motion and rotates the boom reel drum. During deployment, the drum rotates in the unwinding direction and releases the boom into water. During retrieval, the drum rotates in the reverse direction and winds the boom back onto the reel. Rollers and guiding arrangements help avoid twisting, tangling, and uneven winding.

Design Calculation

The preliminary hydraulic drive calculation was carried out using the following input values:

Table 1. Basic Design Inputs

Parameter	Value
Hydraulic motor	OMSU 200
Maximum motor torque	610 Nm at 75 LPM
Motor speed at rated flow	375 RPM at 75 LPM
Available hydraulic flow	15 LPM
Hydraulic pressure	215 bar
Gearbox ratio	6.1:1
Required reel application	Boom reel drive
Target reel speed	Approximately 7 RPM
Target torque requirement	2700 Nm

Motor Torque at Available Flow

The motor torque at 15 LPM was calculated using proportional flow relation:

$T2 = T1 \times Q2 / Q1$

$T2 = 610 \times 15 / 75$

$T2 = 122$ Nm

Therefore, the estimated motor torque at 15 LPM is 122 Nm.

6.2 Motor Speed at Available Flow

The motor speed at 15 LPM was calculated using flow proportionality:

$N2 = N1 \times Q2 / Q1$

$N2 = 375 \times 15 / 75$

$N2 = 75$ RPM

Therefore, the estimated motor speed at 15 LPM is 75 RPM.

Output Reel Speed with One Gearbox

Using the gearbox speed reduction relation:

Nout = Nmotor / Gear ratio

Nout = 75 / 6.1

Nout = 12.17 RPM

Therefore, with one gearbox, the output reel speed is approximately 12.17 RPM.

Output Reel Speed with Two Gear Motors

If the total flow of 15 LPM is divided between two motors, each motor receives 7.5 LPM. The motor speed becomes approximately 37.5 RPM.

RPMout = 37.5 / 6.1

RPMout = 6.14 RPM

Therefore, with two gear motors, the calculated reel speed is approximately 6.14 RPM, which is close to the target controlled speed of 7 RPM.

Output Torque through Gearbox

The output torque through the gearbox is calculated as:

Tout = Tmotor × Gear ratio

Tout = 122 × 6.1

Tout = 744.2 Nm

Therefore, the preliminary calculated output torque is approximately 744.2 Nm. This value is below the target torque requirement of 2700 Nm. Hence, further optimization is required in motor selection, hydraulic flow capacity, gearbox ratio, or multi-stage torque multiplication to fully meet the desired torque output.

VI. Simulation and Structural Analysis

Fusion 360 simulation was used for preliminary structural analysis of the boom reel frame. The simulation included factor of safety visualization, Von Mises stress, first principal stress, third principal stress, and displacement analysis. These simulation outputs help identify the stress concentration zones, deformation pattern, and structural response of the frame under load.

The simulation results indicate that the frame design can be evaluated for load transfer behaviour before fabrication. Stress concentration was mainly expected near support members, welded joints, bearing locations, and load application regions. The displacement plot helps verify whether the structure remains within acceptable deformation limits during loading. Although the preliminary simulation supports the feasibility of the design, detailed validation through physical load testing and dynamic fatigue analysis is required before final industrial deployment.

Experimental Plan

The proposed experimental validation plan includes the following tests:

Table 2. Experimental Validation Plan

Test	**Purpose**	**Expected Output**
Dimensional verification	To check fabricated dimensions against CAD model and tolerance standards	Confirmation of manufacturing accuracy
Weld quality inspection	To detect cracks, porosity, and weld defects	Safe welded structure
NDT testing	To verify critical weld regions	Improved reliability
Torque transmission test	To evaluate torque transfer through motor, gearbox, and reel shaft	Verification of drivetrain capacity
Load capacity test	To check frame response under 3.5-ton equivalent load	Structural stability confirmation
Speed verification test	To check controlled reel speed near 7 RPM	Smooth deployment and retrieval
Emergency stop test	To test braking and safety response	Operator safety confirmation
Vibration observation	To check operational smoothness	Reduced dynamic instability

Cost Estimation

The cost of the boom reel was estimated based on raw material, components, fabrication, machining, surface treatment, assembly, and testing. Major material and component items include square tube 100 × 100 × 5 mm, PL4 plates, reel drum material, SS316L shaft of 70 mm diameter and 150 mm length, UCP-211 pillow block bearings, 3.25-ton shackle, gear mounting kit, M12 and M16 fasteners, welding, cutting, machining, grinding, finishing, NDT testing, primer, anti-corrosion paint, marine coating, shaft alignment, and load/torque testing.

Table 3. Preliminary Cost Summary

Cost Head	**Included Items**
Material cost	Square tubes, plates, drum material, shaft
Component cost	Bearings, shackle, gear kit, fasteners
Fabrication cost	Cutting, welding, machining, grinding, finishing
Inspection cost	NDT testing and visual inspection
Surface treatment	Primer, industrial paint, marine-grade

Cost Head	Included Items
	coating
Assembly and testing	Bearing fitting, shaft alignment, load/torque testing
Estimated boom reel cost	₹1,80,000 to ₹2,50,000

The cost estimation shows that the proposed boom reel can be developed within a moderate fabrication budget for industrial prototype development. However, the final cost may vary depending on material grade, motor selection, hydraulic components, gearbox configuration, surface coating quality, and testing requirements.

VI.RESULT AND DISCUSSION

The design and calculation results are summarized in Table 4.

Table 4. Result Summary

Sr. No.	Parameter	Target / Input	Calculated / Observed Result	Remark
1	Load handling capacity	3.5 ton	Design target considered	Requires physical load validation
2	Target torque	2700 Nm	744.2 Nm preliminary calculated output	Torque optimization required
3	Target speed	7 RPM	6.14 RPM with two motors	Close to target speed
4	Motor torque at 15 LPM	Based on 610 Nm at 75 LPM	122 Nm	Calculated using flow ratio
5	Motor speed at 15 LPM	Based on 375 RPM at 75 LPM	75 RPM	Calculated using flow ratio
6	Output speed with one gearbox	6.1:1 gearbox	12.17 RPM	Higher than target
7	Output speed with two motors	Flow divided equally	6.14 RPM	Suitable for controlled reel operation
8	Structural simulation	Fusion 360 static study	Stress and displacement plots obtained	Useful for design verification
9	Boom reel cost	Preliminary estimate	₹1,80,000 to ₹2,50,000	Prototype-level cost

The results show that the proposed hydraulic drive arrangement is suitable for achieving low-speed controlled boom reel operation. The calculated 6.14 RPM output speed with two motors is close to the required 7 RPM. This is suitable for safe boom deployment and retrieval because excessive speed can lead to uncontrolled winding, boom damage, or operator risk.

However, the calculated output torque of 744.2 Nm is significantly lower than the target torque of 2700 Nm. This indicates that the present drive configuration requires improvement. Possible solutions include increasing hydraulic flow rate, selecting a higher displacement hydraulic motor, using a higher gearbox reduction ratio, using multi-stage reduction, or applying dual motor torque addition with suitable hydraulic power capacity. A final industrial prototype should not be approved only on the basis of the present preliminary torque result. It should be optimized and tested under actual load conditions.

The structural design of the boom reel frame is suitable for further development because it uses a welded steel structure, bracing members, base support, bearing alignment, and corrosion protection considerations. Fusion 360 simulation provides preliminary design confidence by identifying stress and displacement behaviour. The experimental plan also includes dimensional verification, weld testing, load testing, speed verification, and emergency stop testing, which are necessary for validating industrial readiness.

The cost estimation shows that the boom reel structure can be fabricated within an estimated cost range of ₹1,80,000 to ₹2,50,000. This makes the system suitable for prototype-level development and industry-institute project implementation.

VII.CONCLUSION

This paper presented the design and development of a hydraulic powerpack-driven boom reel system for oil spill containment applications. The proposed system addresses the need for fast, safe, and controlled deployment and retrieval of oil containment booms during marine emergency response. The design includes a heavy-duty boom reel frame, rotating drum, support structure, hydraulic motor, gearbox, diesel engine-driven hydraulic powerpack, flow control valve, safety components, and corrosion-protected welded frame.

The preliminary design target considered a 3.5-ton load capacity, 2700 Nm torque requirement, and approximately 7 RPM controlled reel speed. The hydraulic calculation showed that an OMSU 200 motor operating with 15 LPM flow can produce approximately 122 Nm torque and 75 RPM motor speed. With a 6.1:1 gearbox, the output speed becomes 12.17 RPM for one motor arrangement. When the flow is divided between two motors, the calculated output speed becomes approximately 6.14 RPM, which is close to the target speed. The calculated gearbox output torque is approximately 744.2 Nm, which shows that torque enhancement is required to meet the 2700 Nm target.

The Fusion 360 simulation results provide preliminary structural understanding through factor of safety, Von Mises stress, principal stress, and displacement analysis. The estimated boom reel cost is approximately ₹1,80,000 to ₹2,50,000. Overall, the study shows that a hydraulic powerpack-driven boom reel can reduce manual effort, improve operational safety, support controlled boom handling, and provide a practical mechanical solution for oil spill response. Further work should focus on drivetrain optimization, fabrication, load testing, dynamic simulation, corrosion resistance improvement, and full-scale field validation.

Future Scope

Future improvements of the proposed system may include PLC-based automation, remote-controlled operation, real-time load and torque monitoring, IoT-based condition monitoring, solar-powered hydraulic powerpack integration, variable speed control, improved corrosion-resistant materials, lightweight portable design, and integration with oil skimmers and marine recovery vessels. Dynamic FEA, fatigue life analysis, and full-load field testing should also be carried out to validate long-term industrial performance.

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