

Oil and Gas Industry Wireline Large Diameter Split Drum Winch Structure Design and Finite Element Analysis Study

(Gerry), Man Li

Department of Engineering, Rig Pro Painting and Fabrication Inc.

Calgary, Alberta, Canada

gerrymli@yahoo.com

Abstract—in oil and gas upstream industry, hoisting drum winch are essential piece of equipment for both onshore and offshore drilling and service rigs. Large diameter hoisting split drum winch has a wide applications for wireline equipment but with very limited structure design study and very high failure rate due to amount force exerting on its barrel core and flanges. To better resolve this issue, a large diameter split drum winch new structure design study is exploited and a finite element analysis-FEA study is also conducted to guide welding, machining, and manufacturing. Experimental and actual oilfield operational results show that the new structure design for the split drum winch is quite robust and provides good results in terms of reliability and customer satisfaction.

Keywords— oil and gas, upstream, wireline, hoisting, split drum winch, structure, design, finite element analysis, study, large diameter, hoop stress, drum barrel, split flange, wire cable

1. INTRODUCTION

A hoisting winch is a mechanical device that is used to pull in (wind up) or let out (wind out) or otherwise adjust the “tension” of a rope or wire rope (also called “cable” or “wire cable”). In its simple form, it consists of a spool/winch drum with attached power driving and brake systems to sit on its drawwork.

Some of larger drum winches are used in marine applications, and some of them are used in in oil and gas upstream and pipelines applications. These types of applications can require huge tractive forces and the larger drum winches must be of sufficient strength and quality in order to provide reliable service.

An oil and gas upstream industry wide survey revealed that some of large split drum winches have failed during earlier services due to poor structure design and lack of related study to provide any guidance. These failures have exposing the owners to millions of dollars in repair or replacement costs plus the asset downtime and project delay.

For the large diameter split drum winches, the two (2) major structure failures can be classified as drum winch barrel elastic deformation failure or buckling and drum flange splitting with brittle fracture or plastic collapse or excessive deflection of bending due to over load.

There are mainly hoop stress acting on drum winch barrel and forces acting on the drum flanges due to larger quantities of layers of wire cables. Therefore, the strength of large diameter split drum winch material, proper engineering structure design, weld strength, fatigue of welded joint, and high quality of manufacturing are important factors to improve the reliability and high performance of a large diameter split drum winch.

This study project looks at the requirements for the design of hoist drum winch from various design codes based on different industrial applications and carries out a literature review on the subject. Based upon the literature review and drum winch design failure models, a case study where most of large split drum winches has failed with early operational stage due to poor split drum winch structure design is presented and evaluated.

To prevent both drum winch barrel and flange failures and based upon the winch drum stress and deformation behaviors, an optimizing structure design of the large split drum winches with less steel footprint and better manufacturing ability is developed and the finite element analysis is also conducted.

Both the experimental and the actual field operations for total twenty five (25) such new structure designed large split drum winches haven't failed any one of them so far after five (5) years in actual operational services in oilfield.

2. REVIEW OF SPLIT DRUM WINCH STRUCTURE DESIGN

2.1 Applications of Split Drum Winch in Marine, Construction and Oil and Gas Industry

The chain or rope large diameter split drum winches are used in anchoring or mooring in marine industry. The following figure 1 illustrates the main structure of the drum winch application. The anchoring or mooring application defines the wrapping chain or rope around the drum barrel with relative light weight, low stress level and minimum deformation.



Fig. 1 Anchor Split Chain/Rope Drum Winch: Courtesy of DMT Marine Equipment SA

The figure 2 below shows the small diameter split drum winch used in construction hoisting application. This small split drum winch application has the character of light weight, low stress level, and less deformation.



Fig. 2 Split Drum Winch for Construction Hoisting: Courtesy of Kolstrand

The figure 3 below represents the middle diameter split drum winch used in upstream oil and gas industry wireline application. Because there is in need a large hoisting power, it was designed and constructed with heavy barrel core, thicker end flanges and heavier split flange.



Fig. 3 Wireline Heavy Split Drum Winch: Courtesy of Arabian Crane Service L.L.C.

The following figure 4 and figure 5 below depict the middle diameter split drum winches used in upstream oil and gas industry wireline application. Because there are in needs for large winch pulling powers with wire cable, they are designed and constructed with strong barrel core, end flanges and split flange.

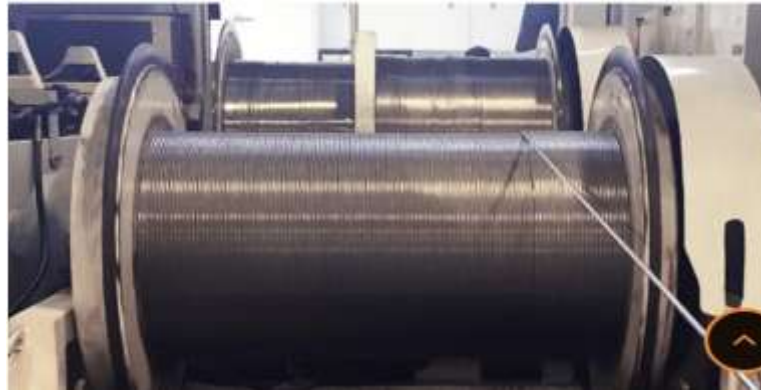


Fig. 4 Double Drum-Wireline Split Drum Winch: Courtesy of Central Cable



Fig. 5 Triple Drum-Wireline Split Drum Winch: Courtesy of Benchmark Wireline Products

The large diameter split drum winch shown on the figure 6 below demonstrates the particular example of the large diameter split drum winch used in upstream oil and gas industry wireline application. As figure 6 displays the heavy duty design intents on barrel core, end flanges with brake bands, and heavy duty split flange between two end flanges to cope with huge amount of tractive forces, hoop stress, flange force, and combination of various driving and brake force.



Fig. 6 Wireline Large Split Drum Winch: Courtesy of Benchmark Wireline Products

2.2 General Review of the Current Drum Winch Structure Design Standards and Codes

The currently design standard literature review looks at published materials relating to the hoisting drum winch. The most common hoisting drum winch design standards are listed below:

- API SPECIFICATION 8A & 8C, Drilling and Production Hoisting Equipment
- API SPECIFICATION 7K, Drilling and Well Servicing Equipment
- ABS Guide for the Certification of Drilling Equipment
- FEM Federation Europeenne de la Manutention (commonly referred to as FEM)
- BS2573-Rules for the Design of Cranes. Specification for Classification, Stress Calculation and Design Criteria
- API SPECIFICATION 2C, Offshore Pedestal-Mounted Cranes
- AS1418, Cranes, Hoists and Winches
- Lloyd's Register Code of Lifting Appliances in a Marine Environment
- DNV Rules for Certification of Lifting Appliances

The literature reviews are focused on the subject of hoist drum barrel and flange forces. The requirements to design a hoist drum barrel and flange from various design codes available are outlined above and are selected from the most comprehensive design codes. The hoist drum strength is normally assessed based on the selected materials, code, and factor of safety to calculate the probability of failure of the drum as an indicator of the hoist drum winch reliability.

The split drum is made up of a barrel, two flanges at both end, and a split flange between end flanges to fit two different wire cables. All flanges are connected to the drum through various manufacturing means. Ideally the barrel and flanges of a split drum can cast as a single unit with desired strength and physical properties. Other methods include welding the flanges to the barrel or bolting it or a combination of the above. The most cost effective ways to manufacturing a split drum winch is to weld the flanges to a barrel. A large split drum winch has been widely used in upstream wireline oil & gas industry because it has the larger capacity drum and it can carry two different wire cables for totally different tasks and applications.

By comparisons of split drum winch shown on above from figure 1 to figure 6, the failure of a large diameter split drum winch are more likely to happen due to poor structure design and combination of various huge forces. When a large diameter split drum winch failure does occur, it has the potential to result in significant damage to the safety, company, economy, and environment and it may also result in harm to personnel in the vicinity. Hence, the a large split diameter drum winch design study has posed to an unique challenge to the upstream oil & gas wireline industry, especially it has not been the subject of oil and gas industry studies in the past with rare and very limited research about it.

Most large diameter split drum winches in upstream wireline oil & gas industry consist of a drum to wind the wire cable and where a number of wire cable layers are required and the end plates (flanges) and split plates (flanges) are fitted. Whilst the effects of wire cables pressure on the drum itself are well researched and understood, the effect of flange forces in large diameter split drum is constantly underestimated resulting in the catastrophic failure of the drum winch. In addition, flanges are also sometimes subjected to forces from driving motor, sprockets, band brakes, brake calipers, clutches or the combinations. These additional forces further complicate large diameter split drum design, and clear guidance on how the large diameter split drum barrel and flanges are to be designed, is not readily available in public domain. The difficulty lies in determining the magnitude and pattern of loading of the large diameter split drum barrel and flanges. Therefore, once the drum barrel and flange force have been determined, the stresses can be evaluated. Then, the challenges would be the design a proper manufacturing process to meet the design intents.

There are some in depth studies about the hoop stresses acting on the drum barrel core. However, the forces acting on the drum flanges are poorly understood even though there are numerous studies have been undertaken to determine the flange forces. Material fatigue is also critical in the reliability of hoist drums as the structure is subjected to cyclic application of stress. Fatigue will result in initiation and gradual growth of cracks until the remaining section of material cannot support the applied service load.

In general, the attachment of flanges to drum barrel is considered as rigid. This would indicate that the drum and flange are cast as a single unit or all attachments need to be full penetration weld.

2.3 The Large Diameter Split Drum Winch Failure Model

According to P. Dietz [Dietz 1971], The loads on a drum are principally the wrapping pressure $p(x)$ on the drum jacket caused by the rope packet and the line loads $F_i(r)$ and $F_j(r)$ caused by the rope layers on the side discs/flanges [1] as shown on Figure 7 below.

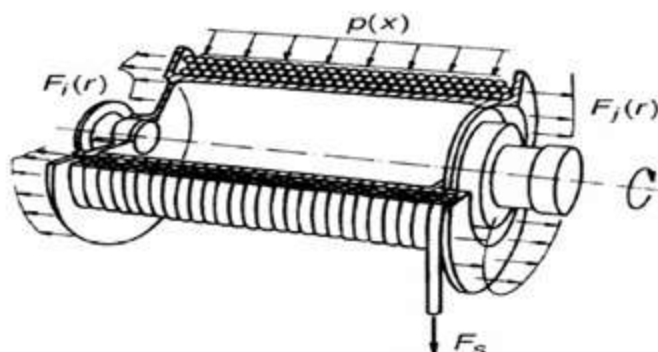


Fig. 7 Rotationally symmetrical pressure and line load distribution: Courtesy of P. Dietz [Dietz 1971], [1]

Based upon P. Dietz [Dietz 1971], The design of drum winch must take into account completely different failure causes explained in Figure 8 below. There are numbers of problem areas: A-drum jacket; B-bearing area (as a result of radial distortion and misalignment); C-mounting restriction in axial direction; D- notch effects in the area of the side disc/flange joints; E-side disc/flange deformation with multiple windings [1].

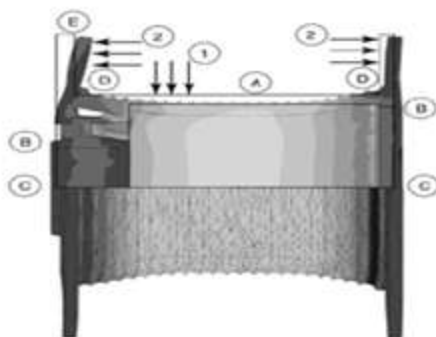


Fig. 8 Winch drum stress and deformation behaviors: Courtesy of P. Dietz [Dietz 1971], [1]

Based upon many studies about the strength of drum winch in the past, it is accepted that a drum winch generally fails in two ways (Song, et al., 1979):

- High wire/rope tensions causing the internal compressive hoop stress in the drum barrel to exceed the ultimate limit strength of the drum material.
- The pressure on the wound wire/rope on the drum flanges causes a high stress concentration at the root or fillet of the flanges. This causes the flange to part from the drum barrel [2].

From the large diameter split drum winch structure design research undertaken during this project, it was found that the magnitude of the drum barrel and flange force varies significantly depending on various split flange characteristics such as wire cable type, drum dimensions, wire cable tension, number of layers of the wire cable and the fleet angle. It was also found that despite significant research and experiments undertaken on the subject, these study findings have not yet incorporated into most design standards. Even though large diameter split drum winch design is a complex subject, it is considered trivial by most design codes and standards because most design codes and standards do not even specify any requirements, such as design safety of factor, for large diameter split drum winch barrel and flange, instead of leaving the design engineer to decide the best way to proceed based on their knowledge and experience. Therefore, there are in need to have more research done and incorporate research and test findings into design codes and standard to guide engineering design and guard public safety.

2.4 The Design Improvement Challenges for the Large Diameter Split Drum Winch

The large diameter split drum winch structure design has its unique design intents due to split flange need to fit into between two end flanges. As the results, there are different hoop stresses on each side of split flange barrel core and different line load on each side of split flanges due to different wire cable. Therefore, the large diameter split drum winch structure design improvement poses unique challenges. It needs to improve its operational safety, strength, manufacturing ability, and long service life span while reducing its carbon footprint and overall cost.

3. NEW STRUCTURE DESIGN STUDY AND APPROACHES

3.1 ABBREVIATIONS AND ACRONYMS

The abbreviations and acronyms are defined as the followings:

- DNV: Det Norske Veritas
- FEM: Federation Europeenne de la Manutention
- ABS: American Bureau of Shipping
- API: American Petroleum Institute
- AS: Australian Standard
- BS: British Standard
- FEA: Finite Element Analysis

Glossaries of Terms are explained as the followings:

Fleet Angle: Angle at which the rope approaches the drum to the drum centre line

LeBus: Winding system on the drum-a designer and manufacturer of drums of all size

Lloyd's Register: A technical and business services organization and a maritime classification society

3.2 Large Diameter Split Drum Winch Barrel Stiffening

For heavier loads, in order to stiffen the barrel core for the large diameter split drum winch, one or two disc ring(s) may be used, spaced a given distance apart as shown below at Fig. 9, (A), (B), and (C). Usually with shaft end, the inner disc along with shaft stub are welded together first as a subassembly unit as shown at Fig. 9, (A). This unit is then welded into the barrel core as shown at Fig. 9, (B), and finally, the outer disc is then slipped over and welded in place as shown at Fig. 9, (C) [3].

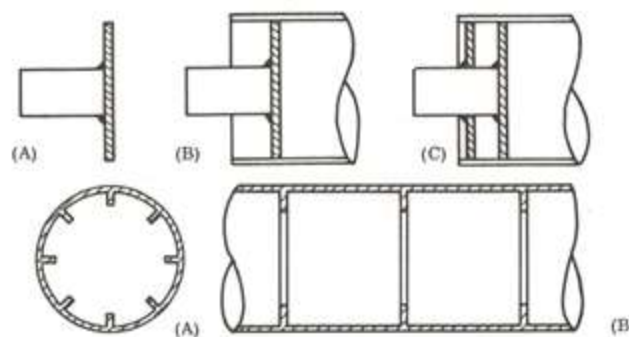


Fig. 9 Drum Winch Barrel Core and Shaft Stiffening [3]

A FEA conducted by LeBus as shown at Fig. 10 below delineates the low stress level after stiffening the drum winch barrel core with a disc ring near the left-side end. On the opposite of near the right-side end, it displays relatively high stress level. The LeBus FEA as shown at Fig. 10 below converges with analysis as shown at Fig. 9 above. That is the same approach used in this large diameter split drum winch barrel core new structure design project.

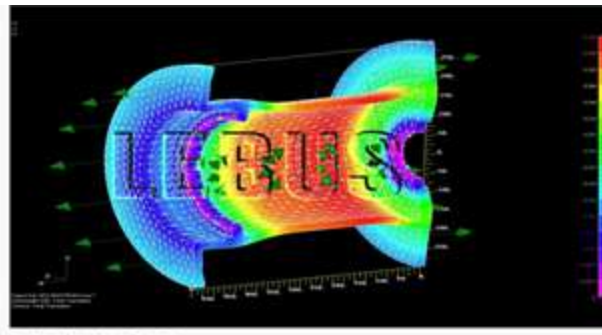


Fig. 10 A disc ring stiffening lowered the barrel core stress level

3.3 Large Diameter Split Drum Winch End Flange Stiffening

There are two scenarios to strengthen the end flanges. One is to utilize the band brake as shown at Fig.6. Another method is to add gusseting plates to reinforce the two end flanges as shown at Fig.11 below [3].

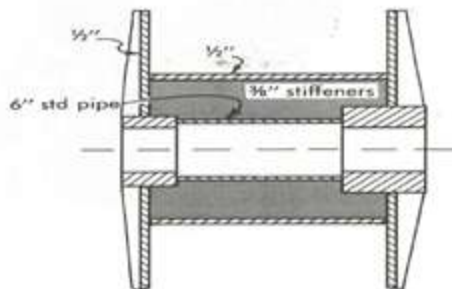


Fig. 11 Drum Winch End Flange Reinforcement [3]

3.4 New Large Diameter Split Drum Winch Structure Design

The innovative strategies for the new structure design of large diameter split drum winch are illustrated as shown at Fig. 12 below. For barrel core stiffening, the combinations of a shaft at left-hand side, 2-end plates, 3-inner disc rings, and gusseting plate around inner barrel core circumference circle at the right-hand side are well utilized to fortify the barrel core because a hydraulic motor needs to be mounted inside of barrel core. Both end flanges are stiffened by the 2-end plates along with band brakes. For the split flange, steel gusseting plates are evenly distributed around barrel core outside circumference and are sandwiched by 2-end split flanges and then welded together as a subassembly unit so that it can be welded on the barrel core outside circumferences. There are also added weldments around touching areas between steel gusseting plates and barrel core outside circumference as shown at Fig. 12 middle section below.

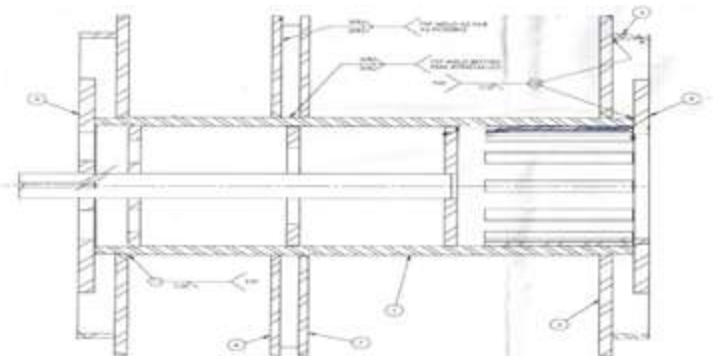


Fig. 12 New Large Diameter Split Drum Winch Structure Design

3.5 New Large Diameter Split Drum Winch Structure Design Finite Element Analyses

As shown at Fig. 13 below, a FEA is conducted based upon the new structure design of large diameter split drum winch as indicates at Fig. 12. The FEA results meet new structure design intents with safety factor of 4.8.



Fig. 13 New Large Diameter Split Drum Winch Structure Design FEA Shown at Hydraulic Motor Drive End

As shown at Fig. 14 below, a case of through drive shaft of the new structure design of large diameter split drum winch FEA is conducted. The FEA results indicate improvement with safety factor of 4.5 as expected.

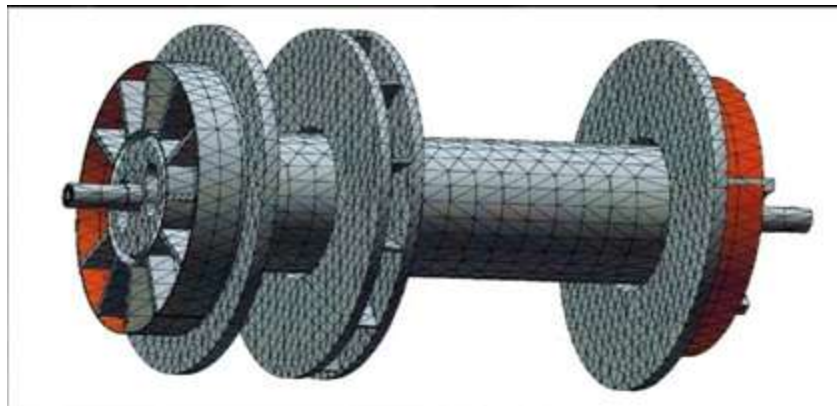


Fig.14 New Large Diameter Split Drum Winch Structure Design FEA with Shaft Drive

As shown at Fig. 15 below, a FEA for smaller band brake at both end flanges of the new structure design of large diameter split drum winch is conducted. The FEA results show with safety factor of 4.4 as expected.

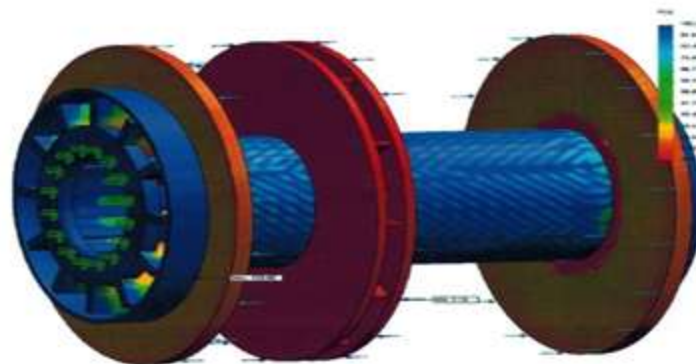


Fig. 15 New Large Split Drum Winch Structure Design with Smaller Band Brake

3.6 Manufacturing Considerations for the New Design

Full penetration welding, proper welding procedure specifications and welding procedure data sheet, and all welding consumables should be used and make sure to comply with American Welding Society or Canadian Welding Bureau or equivalent.

All welders who perform the welding must be a qualified welder as per international standards. To weld the inside of large diameter split flanges subassembly unit to the barrel core, a special long welding special nozzle is needed.

There are many machining processes before and after welding involved to properly prepare and get this large diameter split drum winch manufactured to meet the engineering design specifications. Each subassembly step along with manufacturing sequence and quality control are also critical to ensure high quality products.

3.7 Experimental and Actual Operational Results

After the completion of the new structure design of large diameter split drum winch, we have built and tracked total twenty (25) such new large diameter split drum winch units since. The following Table 1 exhibits the overall experimental and actual field operational results.

Table 1: New Structure Design of Large Diameter Split Drum Winch Operational Results

Numbers of New Drum Winch Manufactured	New Structure Design Split Drum Winch 5 to 7 Years' Operational Results				
	<i>Average Design Factor of Safety</i>	<i>Year of Manufactured</i>	<i>Total Years' in Operation</i>	<i>Customs' Rating (1 to 10)</i>	<i>Number of Unit Failed</i>
7 units	4.26	Year of 2014	7	10	0
8 units	4.51	Year of 2015	6	10	0
10 units	4.68	Year of 2016	5	10	0

3.8 Discussions

Comparison the traditional large diameter split drum winch design shown at Fig. 6 with the new design shown from Fig. 12 to Fig.15, the new design adds more weld strength around touching area between inside split flange and barrel outside circumference. Moreover the new design uses less steel on both end flanges and split flange so it saves material cost and manufacturing time.

4. CONCLUSIONS

This large diameter split drum winch new structure reveals some positive improvements and precautions on the following areas:

- The new design has resulted in enhanced structure and welding strength with high level of reliability and zero failure case so far.
- The new design factor of safety can reach a relatively high level depending on the application and cost. Optimum design factor of safety around 4 to 5 rang would be most cost effective in practical point of view.
- A properly modeled FEA can provide great insights to investigate any weak spot and create innovative solution to eliminate the weakest link in order to meet engineering design intents and specifications.
- All necessary well-developed and tested welding procedure specifications and welding procedure data sheets are needed to guide proper welding processes from start to finish.
- To weld the inside of large diameter split flanges subassembly unit to the barrel core with full penetration weld, a special long welding nozzle is needed.
- Material fatigue is considered the most common cause of structural failure for in-service structural component, subassembly, frame, and/or equipment. Therefore, properly calculation of drum winch hoop stress, flange force, and welding strength to specify suitable material strength and thickness are important.
- High quality of workmanship for welding, machining, manufacturing, assembling, testing, and proper quality control procedures and processes are crucial to ensure high quality and reliable large diameter split drum winch products.

5. REFERENCES

- [1] P. Dietz. (2004). Design Criteria for Multilayer Wound Winch Drum Following Lightweight Design Principles, On, International Design Conference-Design2004, Dubrovnik, May 18-21. 2004.

- [2] Leslie L Moyo. (2009). Structure Reliability Assessment of a Hoist Drum for an Offshore Crane, School of the Built Environment, Heriot-Watt University 2009, pp.12-13.
- [3] Omer W. Blodgett. (1963). Design of Weldments, The James F. Lincoln Arc Welding Foundation, Cleveland Ohio, pp. 5.3-3 to 5.3-10.

Authors



(Gerry), Man Li

Director of Engineering, P.Eng, PMP, MBA
Rig Pro Painting & Fabrication Inc.
Calgary, Alberta, Canada