A SigmaQuadrant Engineering Publication

POSITIVE DISPLACEMENT MOTORS

Theory and Applications

Robello Samuel
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“Great engineering minds march off the maps,
Mediocre engineering minds stay within the boundary,
Small engineering minds never draw the line”

— Ollebor Leumas

Contents

Preface

This book provides detailed theory and working principles of positive displacement motors based on Moineau principle. Our aims are to (1) emphasize the basic principle involved in the operation; (2) instill theory in the operation of the motor; (3) explain the application with reference to drilling framework; and (4) provide the advancement in this area in the recent years. The text is intended for designers, practical field personals, and drilling engineers. It can also be used as a supplement book for downhole drilling tools study and other advanced drilling courses. The mathematics, science, and engineering presented provides in depth understanding of this simple machine but complex intricate geometry. Undoubtedly, analytical and geometrical treatment provided gives a systematic approach for the use under downhole conditions. More advanced treatment with mathematical rigor is also interspersed throughout the book wherever needed and justified. Numerous problems and supplementary problems are given at the end of each chapter so as to give more understanding of the theory presented.

Painstaking efforts have been taken to present usable material; however, errors are sometimes inevitable. We encourage readers to send their suggestions and comments toward the improvement of this book. They can download the errata sheets from the site sigmaquadrant.com.

Authors

Acknowledgments

We thank Kryon Publishing Services (P) Ltd. who helped us with the copyediting and proofreading of this book. We thank Saravanan Boopathy who developed to put together the cover image for this book. We would also like to thank Dr. Hubert (Kannan) Daniel of John Hopkins University and Balaji Srinivasan of Kryon Publishing Services, Chennai for helping us at various stages of the book. Every possible effort has been taken to acknowledge and give appropriate credits in using the copyrighted materials. Should there be any omission, we sincerely apologize for the mistake and suitable corrections will be made at the first possible update.

We would like to dedicate this piece of work to our fellow drilling engineers, technicians, field hands, designers, and manufacturers who have worked on this amazing piece of tool.

About the Authors

Dr. Robello Samuel is a Chief Technical Advisor and Halliburton Technology Fellow with Halliburton since 1998. He helps to lead well engineering applications and is responsible for research in new drilling technologies. He makes decisions and recommendations that are authoritative and have far- reaching impact on research and scientific activities of the company and he serves as a corporate resource, providing technical direction and advice to management in long-range planning for new or projected areas of drilling. He has more than 30 years of multi-disciplinary experience in oil and gas operations, management, consulting, software development, and teaching. His special areas of oilfield expertise include onshore and offshore well engineering, cost estimating, and drilling supervision.

Dr. Samuel has written or coauthored more than 150 journal articles, conference papers, and technical articles and is regarded as one of the world's most influential contributors to advancement of research and practice in drilling engineering. He has given several graduate seminars at various universities and keynote speeches at forums and conferences. Dr. Samuel has been the recipient of numerous awards including the SPE Regional Drilling Engineering Award and the "CEO for A Day (Halliburton)" award. He presently serves as a review chairman on several journals and professional committees. He has been on the faculty of various universities and holds an adjunct professor appointment (concurrently) for the past 12 years, at the University of Houston and Texas Tech University in Lubbock.

Dr. Samuel, a Society of Petroleum Engineer Distinguished Lecturer, holds B.S. and M.S. degrees in mechanical engineering from the University of Madurai and College of Engineering, Guindy. He also holds M.S. and Ph.D. degrees in Petroleum Engineering from Tulsa University.

Dr. Samuel's unique blend of skills as a field engineer, researcher, and instructor has helped him author 10 drilling books and a forthcoming book "Drilling Engineering Optimization." He can be reached via e-mail at robellos@hotmail.com or phone at (832) 275-8810.

Dr. Dmitry F. Baldenko, doctor of technical sciences, is an active member of the Russian Academy of Natural Sciences. He graduated from Moscow Oil Institute named after Gubkin (now Russian State University of Oil and Gas) with specialty in "Machinery and Equipment of Oil and Gas Fields."

From 1957 to 1969, D. Baldenko was a lead designer for production of rodless pumps and participated in the creation of single-screw submersible pumps for oil production and water lifting and other oilfield machineries. Since 1969, D. Baldenko has been working for the Russian Scientific Research Institute of Drilling Techniques (VNIIBT). As a chief designer of screw-type hydraulic machinery, he was directly involved in design, testing, and implementation of multi-stage positive displacement motors (PDMs). As one of the inventors of Russian PDM, D. Baldenko established initial contacts between Russian and western companies to promote this technology in the western markets.

He was the first to propose and demonstrate the advantages of multi-lobe progressive cavity pumps, as well as a scheme of submersible hydraulic drive screw pumping unit for oil production.

Dr. Dmitry Baldenko authored 200 scientific publications, including 12 books and reviews in the area of drilling and oilfield technology and is the owner of more than 250 Russian and foreign patents for invention.

Dr. Fedor D. Baldenko, in 1980, graduated from the Moscow Institute of Petrochemical and Gas Industry named after Gubkin with specialty "Machinery and Equipment of Oil and Gas Fields" and is constantly working in this institution (now Russian State University of Oil and Gas).

As an associate professor of the oil and gas industry machinery and equipment department, F. Baldenko gives courses on "Machinery and equipment for drilling oil and gas wells", "Installation and operation of drilling and oilfield equipment" and "Hydraulic machines and compressors." He conducts research in the field of operation of single-screw hydraulic machines, theory cycloidal gearing, geometry optimization of screw working bodies, modeling of dynamic systems of drilling, and oilfield machinery.

F. Baldenko has authored 120 scientific publications, including 8 monographs and reviews in the area of drilling and oilfield equipment. He is also the author of more than 50 patents for invention.

CHAPTER 1

General Introduction

Selection of proper downhole motor is important in designing the bottomhole assembly (BHA) with mud motors. Improper designs may lead to costly problems such as wellbore crookedness, improper build rate, and string failures. One of the components in the BHA is a downhole motor. Before going through in detail about the working principle, position of the motor in the BHA, and operating parameters few basic terms need to be understood. This chapter outlines the basic terms involved in the wellpath and motor design.

PUMPS AND MOTORS

A hydraulic pump converts mechanical power into hydraulic power. The input of mechanical power into the pump is the product of the angular velocity of the pump and torque, whereas the output hydraulic power is equal to the volumetric flowrate and the pressure drop across the pump as shown in Fig. 1.1.

Hydraulic motors can be broadly classified as shown in the chart (Fig. 1.2).

Hydraulic motors are used to turn hydraulic power into rotary motion and they can be classified as

- Gear motors
- Vane motors
- Gerotor motors

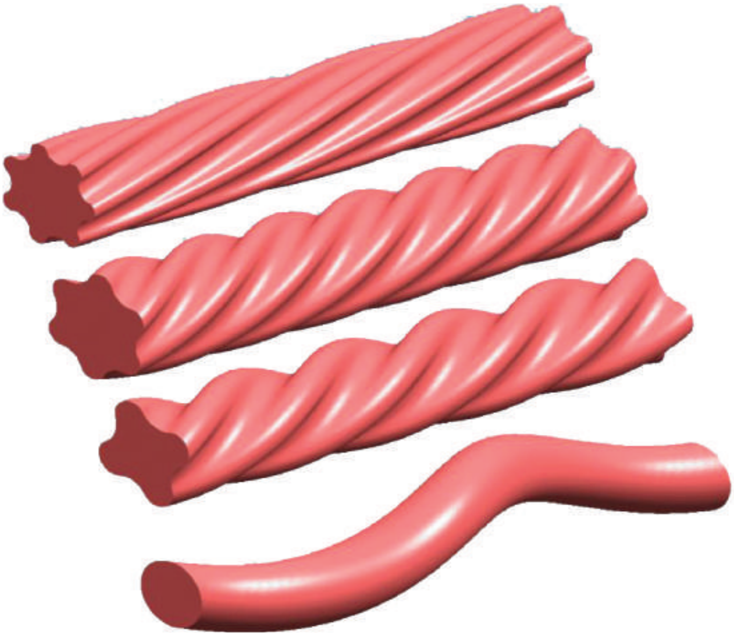

Figure 3.8 Rotor cross-section.

As the number of lobes increase the speed decreases and torque increases.

Universal Joint

Eccentric rotation of the rotor is converted to concentric rotation by the use of a universal joint or a flexible joint, and an adjustable universal drive shaft is shown in Fig. 3.9.

Adjustable Bent Housing

It is an option to provide wide range of build rates with the motor. Different manufacturers provide different adjustment settings.

Bearing Assembly and Drive Shaft

The axial load is transmitted to the bit through the thrust bearing assembly. The drive shaft rotation is made smooth by radial bearings.

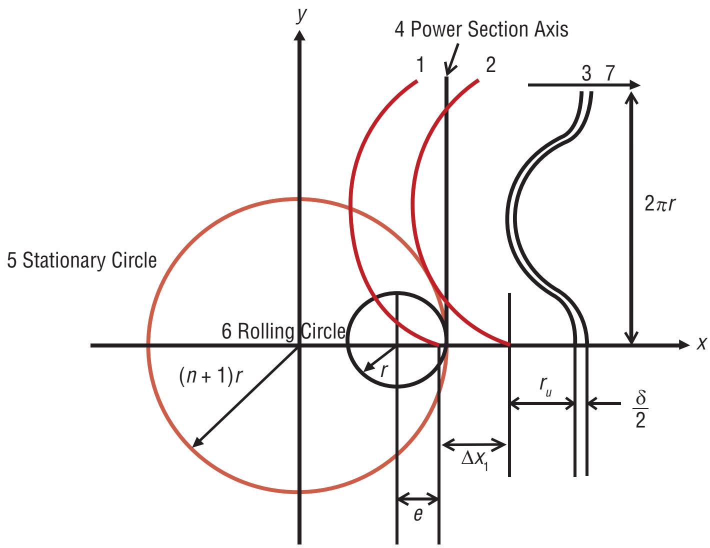

Figure 4.20 Formation of the conjugate profile with interference.

The chart description is as follows: 1 – shortened cycloid, 2 – offset cycloid, 3 – equidistant, 4 – motor axis, 5 – stationary circle, 6 – rolling circle, 7 – resulting position rack.

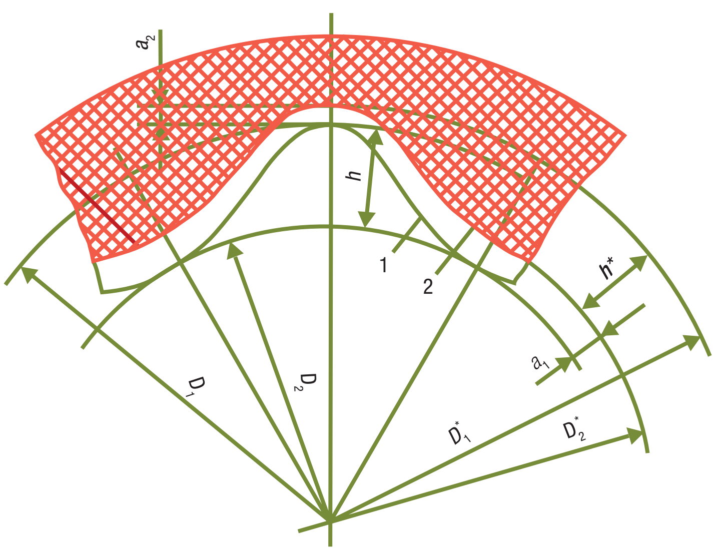

Figure 4.21 Shrinkage profile of stator.

1 - the nominal profile, 2 - the actual profile.

III. Calculation of axial forces
IV. Calculation of rotor and the motor output rotor
V. Calculation of rotor section
VI. General design of components
VII. Calculation of deflection layout

The details of the design in the respective categories are explained in detail.

I. Calculation of the geometric parameters of the power section (rotor and stator)

1. Outer diameter of the motor stator *D* (Fig. 6.1)

To provide the necessary clearance (gap between the borehole wall and the motor stator) that can be calculated using the simple equation:

$$D = (0.8 \text{ -> } 0.9)\, D_h \tag{6.1}$$

2. Pitch circle diameter of the stator

$$D_c = D - 2(\varepsilon_M + \varepsilon_p) \tag{6.2}$$

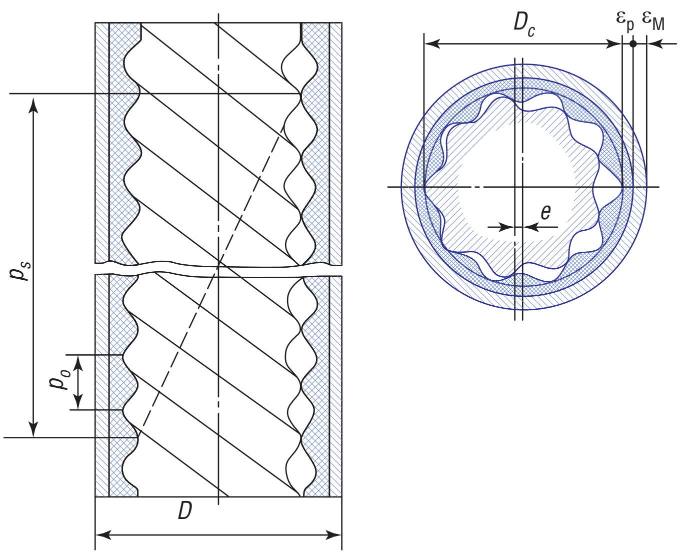

Figure 6.1 Outer diameter of the motor stator.

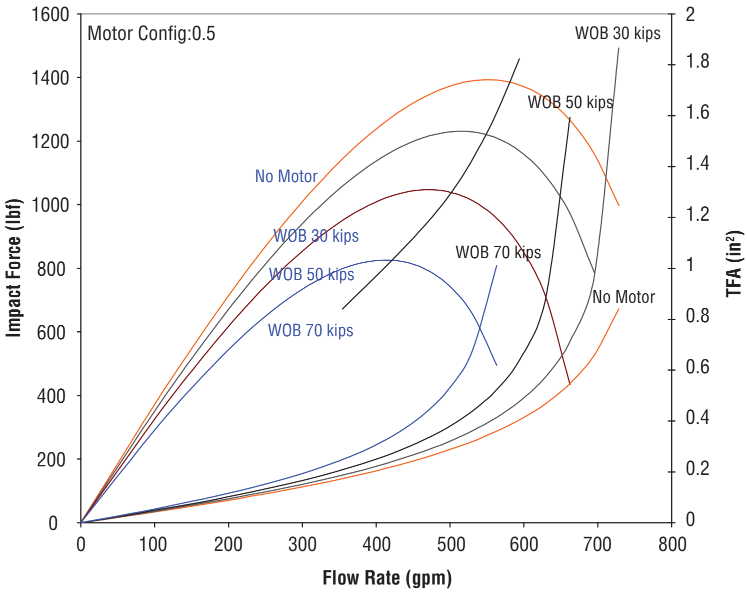

Figure 9.20 Impact force vs flow rate.

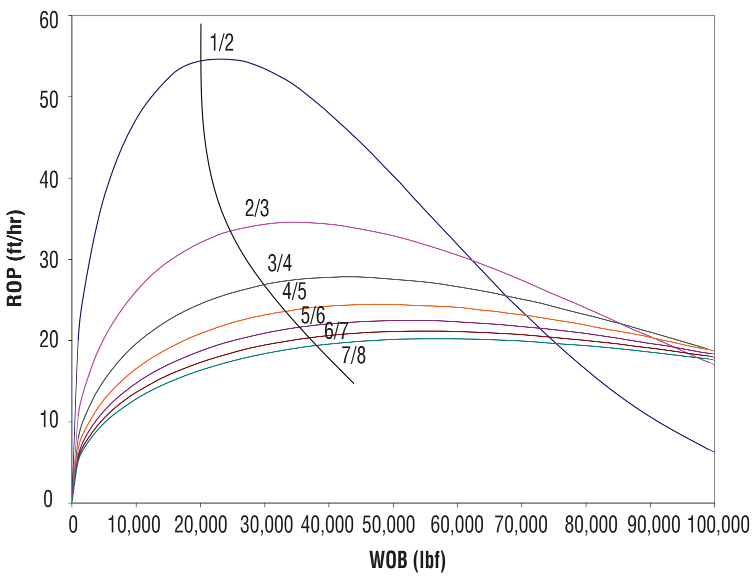

Figure 9.21 ROP vs WOB.

The resultant force acting at the contact point is given by

$$F_n = \pi L(S) d_s i \sqrt{\Delta p^2 + \left(\frac{d_s^2}{\sqrt{2}} \rho_s^2 e N^2 \right)^2} \tag{11.4}$$

where

i = winding or configuration ratio

$i = \dfrac{n}{n+1}$

n = number of rotor lobes of the motor (winding number)

Because of the contact forces, the piezoelectric material undergoes strain as shown in Fig. 11.5 for a 3:2 lobe motor. The number of piezoelectric material embedded in the motor will also be a function of the number of lobes in the power section of the motor.

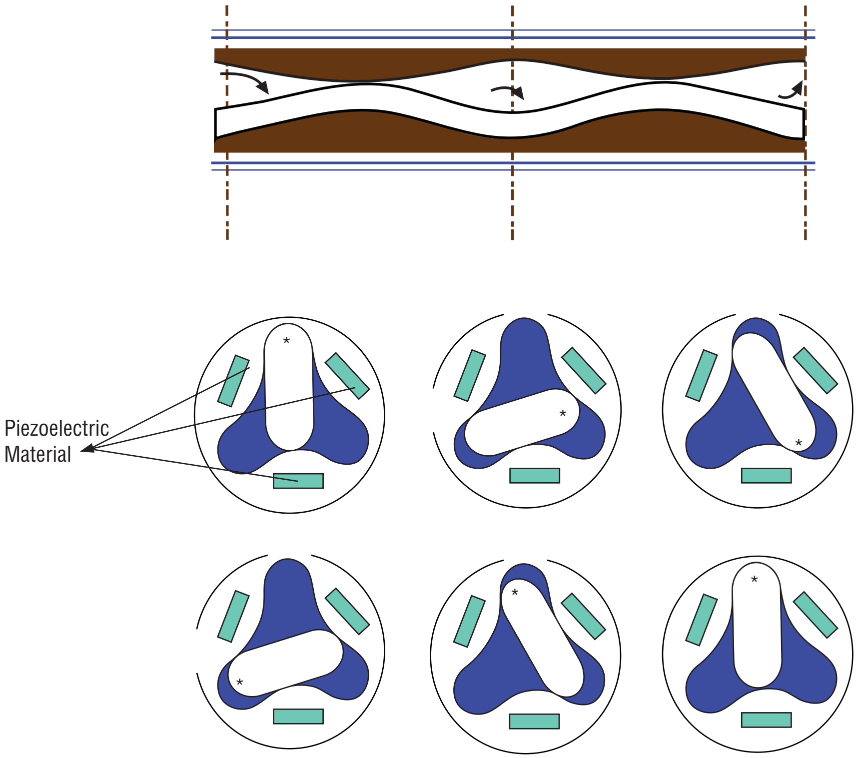

Figure 11.5 Piezoelectric material placements for 3:2 lobe motor.

About the Authors

Dr. Robello Samuel has been a Chief Technical Advisor and Technology Fellow (Drilling Engineering) working with Halliburton since 1998 in Houston. He is currently a research and engineering lead for well engineering applications and responsible for research and scientific activities for new drilling technologies. In his present role he also conceives and develops creative/innovative technology and drilling solutions critical to the company's success. He has more than 30 years of multi-disciplinary experience in domestic and international oil/gas drilling operations. He has been an adjunct Professor at the University of Houston for the past 12 years teaching. He has published more than 150 technical papers, reports and 10 books. He started his career working on rigs as a drilling engineer. He holds BS and MS degrees in mechanical engineering, as well as MS and PhD degrees in petroleum engineering.

Dr. Dmitry F. Baldenko, graduated from Moscow Oil Institute (now Russian State University of Oil and Gas) with specialty in "Machinery and Equipment of Oil and Gas Fields." From 1957 to 1969, he was a lead designer for production of rodless pumps and involved in the development of single-screw submersible pumps. Since 1969, he has been working for the Russian Scientific Research Institute of Drilling Techniques (VNIIBT). As a chief designer he was directly involved in design, testing and implementation of multi-stage positive displacement downhole motors (PDM). He authored 200 scientific publications, including 12 books and holds more than 250 Russian and foreign patents.

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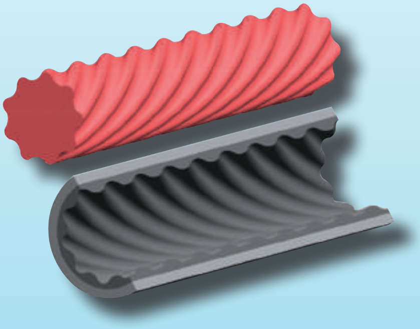
A comprehensive and valuable book written by a team of outstanding experts in this tool and published through SigmaQuadrant publishing. The *Positive Displacement Motors* covers the full spectrum of topics in terms of analysis and design of the downhole mud motor that serves the workhorse of the downhole drilling system for several decades. This book presents functional, operational and technical aspects of positive displacement motor. It provides a platform ideal to seasoned engineer, experienced researcher and other professionals involved in the drilling operations as it offers real insight into this simple but complex machine. It highlights the background and development of this tool

- Provides details of the design
- Offers operational guidelines of this tool
- Emphasizes technology selection and innovation in the offing
- Incorporates practical operating envelop



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