OPTIMIZATION FOR SOME DESIGN ELEMENTS OF THE DRILL STRING

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Abstract. *The successful design of a drill string consists in taking into account, separately and as a whole, the following major considerations: the well - as an architecture objective; the operations - as scenarios for mechanical, static, dynamic and fatigue loads and stress of the drill string; technical capabilities - as technological support for the successful implementation of the proposed operations; risk factors - as a support in assessing them for upgrading or downgrading the chances of occurrence. In the same time, the design of the drill string must be seen in close correlation with its operation and inspection. This is owing to the fact that the major objective of the design is, finally, to maintain its structural integrity during operations in such way that the drill string ensures the functions for which it was designed, under maximum safety conditions. These aspects are, in fact, the subject of study of this research.*

1. The marking of the drill pipe and tool joints

Given the multitude of drill pipe and special connections manufacturers, on one hand, and the fact that the drill pipe with their connections can be used anywhere in the world, on the other hand, the API by RP7G Specification has conceived an unified and standardized marking system for Drill pipe and special connections, making possible their easy and without error identification.

In addition, the owners of these drilling string elements may enter their own marking system, which is to be used more likely for quick identification for those elements requiring inspections, repairs, or which must be downgraded from their original category of Resistance or Initial Mechanical Characteristics.

The practice recommended and adopted by most drilling contractors is to identify each piece of the drill pipe after purchase, through a series of numerical alpha characters. The marking the drilling pipe is important because it:

- Locates possible causes of technical incidents;
- Prevents and/or minimizes damage of the drilling string in the well;
- Warns and triggers on the moment of change of the drill pipe position within the drilling string;
- Enables the recording of the operations type carried out by a drilling pipe, hence the type of mechanical loads and stress to which it has been exposed;
- Determines the drill pipe life for a certain classification thereof, etc.

Figures 1 and 2 below present, schematically, the template for marking and identifying the drilling pipe and special connections.

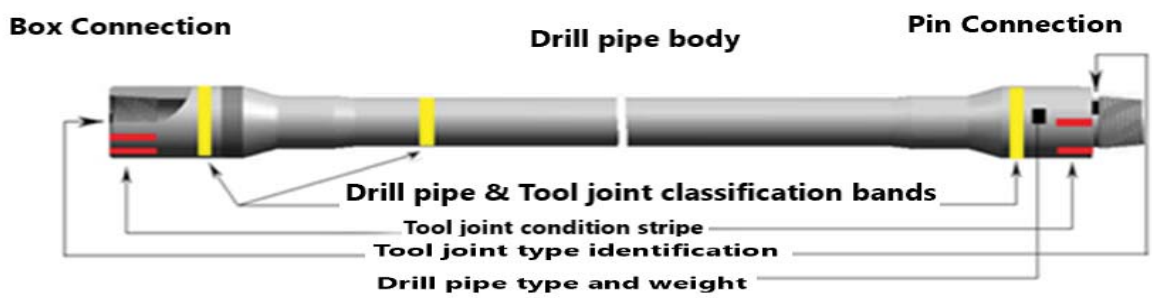

Fig.1 *Drill pipe marking* [1]

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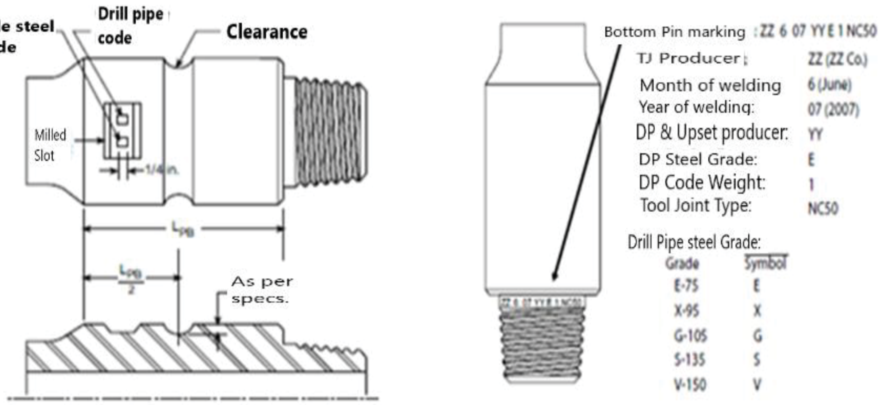

Fig.2 *Marking & identification of the tool joints* [1]

2. General elements used in drilling string design and optimization

In the sizing process of the drilling string, the essential premise is that the drilling string must fully retain its structural and dimensional integrity during its exploitation, while ensuring all the functions for which has been designed.

In fact, the sizing of the drilling string is the selection of those dimensions, i.e. internal/external diameters, steel grades, elements lengths and so on, as a result of anticipated mechanical loads in such way that during its exploitation, the drilling string is permanently run below the allowable limits of simple or/and combined mechanical loads: traction, compression, torsion, bending, external pressure, internal pressure, vibration, corrosion, buckling and fatigue. In the same time, its structural integrity must be permanently assured.

In order to successfully design a drilling string, the following major aspects should be viewed, separately and as a whole: the well – as a construction goal; the operations – as scenarios for drilling string's mechanical, static, dynamic stress and fatigue loads; the technical capabilities - as a technological support to successfully achieve the proposed operations; the risk factors – as support in selecting methods to eliminate/reduce them.

The well - as a construction goal / objective:

In this case, the following input data should be taken into account:

- ✓ True vertical depth of the well;
- ✓ Measured depth of the well;
- ✓ Horizontal well displacement (step out);
- ✓ Deviation intensity (dog leg severity);
- ✓ Drilling diameters per each drilling phase;
- ✓ Drill bit types proposed for operations, including the recommended drilling parameters as: weight on bit, RPM, flow rate;
- ✓ Drilling fluids types, including their rheological parameters;
- ✓ Type of fluids encountered and their corrosiveness while drilling as hydrocarbons, H_2S, CO_2, NaCl, KCl_2 etc.;
- ✓ The rocks' characteristics which are to be drilled by each drilling phase;
- ✓ The drilling technology proposed for use;
- ✓ Drilling rate / rate of penetration and the drilling time;
- ✓ Estimated friction coefficients in open hole and in cased hole;
- ✓ Pore pressure gradients, fracture gradients, geothermic gradients.

Operations – As scenarios for drilling string's mechanical, static, dynamic, stress and fatigue loads:

- Motor Drilling and/or rotary drilling at the final depth for each drilling phase*;
- Sliding / Directional drilling*;
- Rotating off bottom with circulation at bottom for each drilling phase*;
- Reaming downward hole using the rotary table*;
- Reaming upward hole using the top drive system*;
- Hole opening to a bigger diameter (per intervals);
- Pull up weight and slack off weight to bottom per each drilling interval*;
- Lainer setting with or without rotation;
- Drill Stem Testing
- Cementing Liners and / or setting cement plugs for special purposes;
- Stuck Drilling string – Jarrimg operations;
- Fishing and Milling Operations;
- Packers and other bottom hole tools setting;
- Tubing Conveyed Logging operations via drilling string;
- Continuum mchanical coring; etc;

* *MANDATORY loading scenarios*

Technical capabilities - as a technological support to successfully achieve the proposed operations:

- The drilling rig (maximum hook load; draw work power; rotary table type and capability, top drive system type and capability, mud pumps power and capability, BOP system type and capability);
- Down hole tools, equipment and devices, which shall be used: types, requirements, capabilities, limits, (positive displacement motors, turbines, stabilizers, hole openers, reamers, impact tools, jars, accelerators, bumpers, friction reducers, vibration attenuators, core barrels, liners running tools and hangers, fishing and milling tools).

Risk factors – as support in selecting methods to eliminate/reduce them:

- Geological risks: pressure anomalies, temperature anomalies, tectonic stress, faults, fractures, salts, H_2S, CO_2;
- Financial and logistic risks: required equipment is very expensive or unavailable at the operations start up;
- Human nature risks: equipment under sizing, incorrect decisions, undervaluation or over-evaluation, delays in decision, omissions, misinterpretations, ineffective communication.
- Risks related to getting stuck in the hole: key seat, differential stuck, mechanical stuck, holes collapse, dropping objects, etc.

Designing a drilling string involves optimizing all four above aspects, even if in practice, there are often contradictory situations that need to be solved simultaneously.

The design of the drilling string is done by elements on each drilling section of the well bore, this being an integral part of the Well Design Package.

It is an iterative process, in the way that the drilling string components are selected, by the verification for their maximum allowable mechanical loads, and if their Minimum Allowable resistance conditions are not met, more resilient components are reselected and re-verified again until the mechanical conditions are met. [2].

In the same time, the design of the drilling string must be seen in close correlation with its exploitation and inspection.

This is because the major objective of the design is ultimately to maintain its structural integrity while operations are in progress as well that the drilling string is assuring maximum safe operating conditions, and keeping non affected all functions for which it has been designed.

3. Mechanisms triggering the drilling string damages

According to the DS-1 standard, edition 3 [2], there are two major mechanisms that ultimately lead to the damage to the drilling string: **overload** and **fatigue.**

Overload is a classic mechanism approached according to the theories of material strength, the components of the drilling string being designed to support the anticipated mechanical loads during exploitation. This approach, based on mathematical models and theoretical formulas, is now well-known and successfully verified in practice. Therefore, a design based on this mechanism will give safe results [2].

Fatigue is a mechanism that, although it is demonstrated as an occurrence in practice (causing many problems), has a much less known theoretical support. The phenomenon is induced by cyclical mechanical loads, which take place over long periods of time, and which is rapidly increasing in the corrosive environment by triggering of initial micro-cracks within the respective components. The destruction of an element of the drilling string caused by fatigue may even occur at only 10 – 20% of the Yield limit of the material [2].

The fatigue as phenomenon is particularly complex, it can be initiated as an occurrence to certain points – stress concentrators, and then propagating exponentially and extremely rapidly, causing the complete damage to the subject component. For this reason, the mechanism should be regarded as a cumulative process in time. As a result of his complexity, this mechanism is hard to predict accurately and, as a result, mathematical modeling becomes extremely complex and often inaccurate. With a major impact on material mechanical resistance, fatigue is taken into account by any means so that the damage caused by this phenomenon may be reduced as much as possible [2].

Design factors or safety factors in design *[2]*

Safety factors (mainly tensile, torsion internal pressure, external pressure and buckling) are applied in drilling string design in order to satisfy the design limitations, for each drilling string element.

Safety factors shall be used for each element of the drilling string so as to having, during exploitation, sufficient margin for the mechanical loads of the drilling string.

The buckling safety factor is used to ensure that there is a sufficient margin in the weight of the bottom hole assembly (BHA) in order to avoid the buckling in drilling string and impact tools, under the influence of mechanical compression.

Typically, these safety coefficients have values between 1 and 1.3 (higher-value coefficients mean a more conservative project) [2].

Design constraints

Design constraints are criteria which a drilling string design has to meet in order that the design is safe.

Standard DS-1, Ed.3 recommends two design constraints for overload:

The minimum supplementary tensile and the maximum loading factor.

Table 1. *Overload Design Factors*

Factor	Design Group		
Design Factors	**1**	**2**	**3**
Tension and comb Loads	>=1,25	>=1,15	>=1
Torsion	>=1,2	>=1,2	>=1,2
Maximum Load Factors	<=100%	<=100%	<=100%
Minimum Overpull	>=15%	>=15%	>=15%
Inspection Categ.	N/A	>=3	5

They also recommend four design limits regarding the fatigue design: bending strength ratio (BSR); stiffness ratio (SR), curvature index (CI) and stability index (SI) [2].

Bending stress ratio (BSR) is used for pin-box connections on the tubular with a high degree of stiffness as drill collars, down hole motors, stabilizers, reamers, hole openers. Is not applicable for heavy weight drill pipes (HWDP) and drill pipes, except for HWDP pins screwed out to a drill collar box. The BSR values are calculated for each connection type corresponding to each diameter of drill collar.

As an effect, a balanced BSR will have a higher degree of fatigue stress resistance for the pin and the box (fig.3). [2]

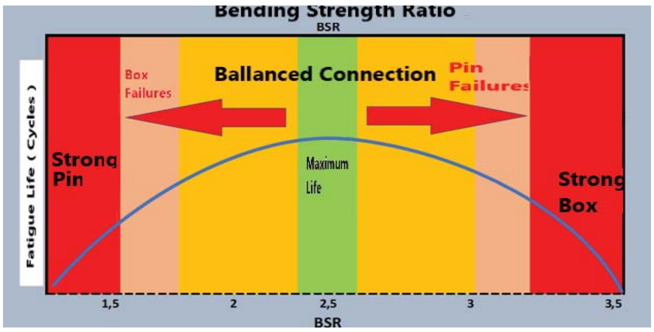

Fig. 3 *Balanced connections*

Stiffness ratio (SR) shall be applied to the change of the areas of the sections for the elements of the bottom hole assembly (BHA) from the drill collars to the drilling pipe (not applicable to the section changing the drilling pipe) [2].

Maximum curvature index (CI) shall be applied at the body of the drilling pipe that rotates in curved / directional bore hole sections, and considers the curvature of the bore hole, the diameter and the weight of the drill pipe, the steel grade, the wear class and the axial load in studied section. Because the axial load plays an important role in fatigue resistance, curvature index is calculated both for the drilling scenario and the upward correction (back reaming) [2].

Maximum stability index (SI) applies to the BHA elements as drill collars and HWDP, which are in buckling. It is a relative quantitative measure of the fatigue resistance for the BHA elements in the state of buckling [2].

Shortly, Table 2 highlights the safety coefficients and design limitations, while Table 3 recommends BSR values.

Table 2. *Safety factors and design constraints [2]*

Factor or Constraint	Group Design 1	Group Design 2	Group Design 3
BSR	Table 2		
SR	< = 5,5	< = 5,5	< = 3,5
CI	< = 20000	< = 10000	< = 6000
SI	< = 1000	< = 600	< = 200
DFBHA	> = 1,15	> = 1,15	> = 1,2

Table 3. *BSR Recommended values [2]*

Strong pin nominal diameter, in	BSR traditional values	BSR recommended values
< 6	2,25 - 2,75	1,8 - 2,5
6 – 7 7/8	2,25 - 2,75	2,25 - 2,75
= > 8	2,25 - 2,75	2,5 - 3,2

4. Design Groups

It is, in fact, a way of simplifying the 'design philosophy' by grouping the design limitations and safety coefficients, so that the projects can be compared and the drilling strings are allocated from the beginning to certain types of specific projects. In the same time, the required inspections for drilling string elements must conform to a certain types of projects.

Table 5 presents the application of safety coefficients and design limitations (DS-1 TM, Ed.3).

Table 6 presents the factors and design constraints for 3 design groups as per (DS-1 TM, 3rd edition) [2].

Table 4. *Design Groups*

Considerations	Design Group		
	1	**2**	**3**
Cost of Failure	Low	Mod	High
Failure exp.	Low	Mod	High
Org. Risk tolerance	High	Mod	Low

Table 5. *Applicability of design factors and design constraints (DS-1, 3rd edition) [2]*

Design Activity	Overload Design	Fatigue Design
Configuring the BHA for structural Soundness	• Load factor • Minimum over-pull • Safety factors for traction and torsion	• Bending Strength Ratio (BSR) • Stiffness Ratio (SR) • Stability Index (SI)
Configuring drilling gasket	• Load factor • Minimum over-pull • Safety factors for traction and torsion	Curvature Index (CI)

Table 6. *Design factors and constraints for DS-1 design groups [2]*

Activity	Design Factors or Constraints	Design Group		
		1	**2**	**3**
Overload Design	Design Factor for Tension (DFT)	> = 1,25	> = 1,15	> = 1
	Design Factor for Torsion (DFTR)	> = 1,2	> = 1,2	> = 1,2
	Maximum Load Factor	< = 100 %	< = 100 %	< = 100 %
	Minimum Over-pull	> =15 %	> = 15 %	> = 15 %
Fatigue Design	Bending Strength Ratio (BSR)	Tabelul 2	Tabelul 2	Tabelul 2
	Maximum Stability Index (SI)	< = 1000	< = 600	< = 200
	Maximum Curvature Index (CI)	< = 20000	< = 10000	< = 6000
	Stiffness Ratio (SR)	< = 5,5	< = 5,5	< = 3,5
	Design Factor for BHA Weight (DF BHA)	> = 1,15	> = 1,15	> = 1,2
Inspection Program	DS-1 Category	N/A	> =3	5
	Max. Slip cut severity (% of adjacent wall)	< = 10	< = 10	< = 5

Figures 4, 5 and 6 present the schematics for the flux of the drilling string design for overload, fatigue and the locations of the four fatigue design constraints along of the drilling string and BHA [2].

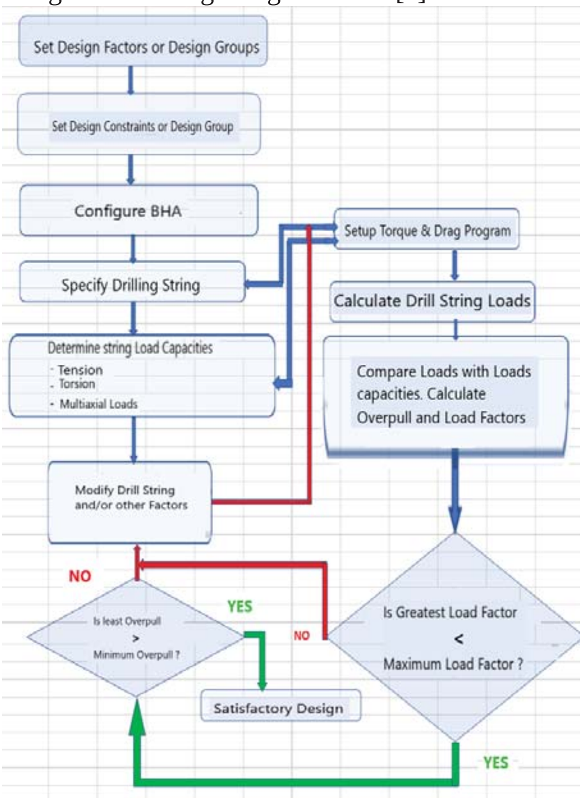

Fig.4 . *Drilling string overload design process [2]*

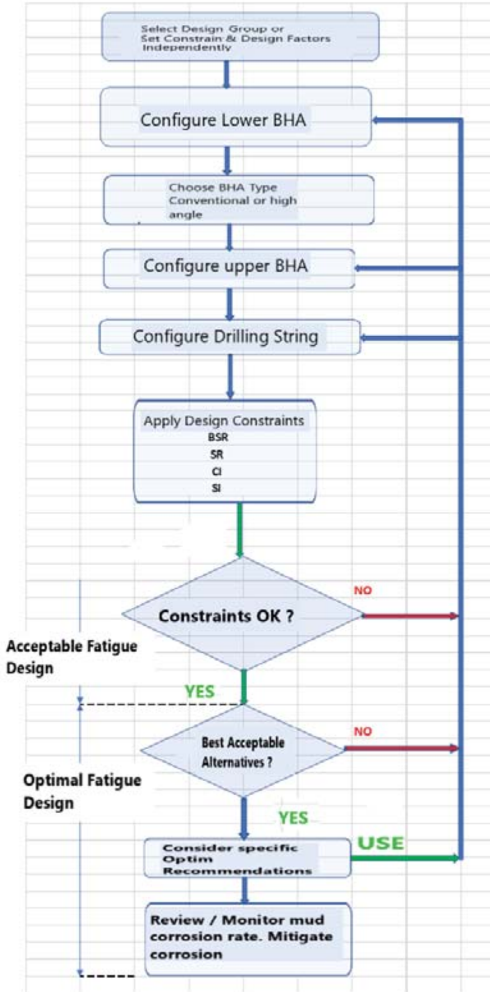

Fig.5 *The fatigue design process [2]*

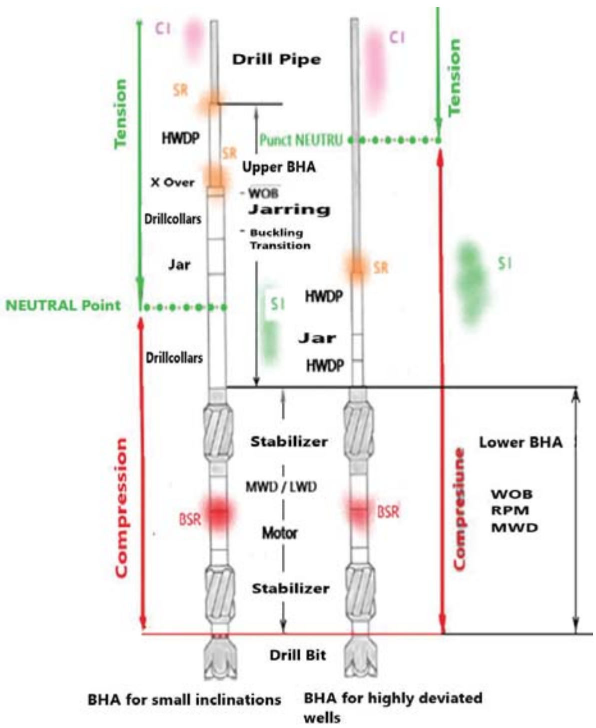

Fig.6 *Location of the four constraints in fatigue design along of the drilling string and BHA [2]*

5. Conclusions and proposals

- Drilling pipe marking is important, because it locates possible causes of technical incidents, warns of the moment of changing of the drill pipe position within the drilling string, gives the possibility to record the types of operations carried out by any drill pipe, hence the type of loads to which it was exposed, etc.;
- During the design process of sizing the drilling string, the essential premise is that it must fully keep its structural and dimensional integrity during its exploitation, while ensuring all the functions for which has been designed;
- The design of the drilling string must be seen in close correlation with its exploitation and inspection. This is because the major objective of the design is ultimately to maintain its structural integrity while operations are in progress such that the drilling string ensuring, the maximum safe conditions, and the functions for which it has been designed;
- As per DS-1, 3rd ed., they recommend two design limitations for overload: minimum over-pull and maximum load factor, respectively four design constraints for fatigue design are recommended: bending strength ratio (BSR); maximum stiffness ratio (SR); maximum curvature index (CI); maximum stability index (SI) [2];
- They present the drilling string overload design process diagram, the drilling string fatigue design process diagram, and the location of the four limitations on fatigue in the drilling string and BHA [2].

Selective Bibliography

1. ***
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2. ***
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