Applied methodology to design a machine to test the strength of offshore synthetic mooring ropes

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ABSTRACT. The technology of platform anchorage systems has been developing quickly nowadays. Due to the oil extraction in deep waters, the traditional anchorage types, such as anchor cable/wire rope/anchor cable, in the shape of a catenary, were replaced by an anchorage named "Taut-Leg". This new way of anchorage, characterized by an anchor cable/synthetic cable/anchor cable, operates in a straight mode, thus reducing weight and providing an easier mooring operation. In addition, the synthetic ropes for platform offshore anchorage are long and robust, with higher number of sub ropes arranged in a parallel mode in order to increase mechanical strength. PETROBRAS has used this new form of technology since the beginning of this decade with polyester cables, and, despite this, there is a lack of knowledge about the behavior related to structural integrity (residual life, total life, etc.). Taking these needs into account, PETROBRAS and POLICAB have been interested in developing a test machine which will be capable to execute static rupture tests (maximum value of 300 ton) and fatigue tests (150 ton). Both tests will be applied to sub ropes, simulating the environment conditions (sea wave frequency and storm displacement). The main objective of this paper is to present the methodology used for choosing the best equipment which meets our needs, from the creative process to the conception of the equipment.

KEYWORDS. Test machine; Sub ropes; Methodology; Mooring ropes.

INTRODUCTION

Nowadays the platform anchorage for extraction/drilling as production in deep water and ultra-deep water is done mostly using synthetic ropes. The anchorage system described is a very recent technological innovation (last 10 years), mainly developed to be used in systems which operate in deep water. In spite of the system being redundant and elaborated by several ropes and where each rope is built by several sub ropes in parallel it is still a possible weak link at the structural integrity chain due its large responsibility to avoid accidents in the whole system.

Despite the studying developed nowadays it is unknown the relation between the rupture load of a rope used and its durability into operational usage. Besides this, the gotten information are specific for each rope in function to the characteristics of working on set by its own design building (bent, twisted, etc.) such as the relation between the loading capacity and stretch. That worry about the need to better know the behavior of these ropes along the using time it is the main reason to create the machine that it is under development by POLICAB- Stress Analysis Laboratory requested by PETROBRAS. It is still intended to set a procedure what be possible besides to determine the residual life of synthetic ropes at usage and also to check and to evaluate the life of the new ropes since their installation. The final results will be relevant for platforms and other floating systems of the gas and oil industry that operate in deep water and ultra-deep

water. To know without a mistake the residual life of a specific anchorage rope, of high responsibility, it is a warranty of safety for the whole floating system. So, it is necessary to build up a rupture and fatigue test machine for synthetic sub ropes with a 300 tons capacity. POLICAB will be set as the reference in the research for the structural integrity of synthetic ropes.
The complexity engaged in developing a machine sized like that requested to apply a methodology of decision in the creative process of the equipment. For so many commercial and non-commercial possibilities to assemble it, the application of the process was limited to the better assembling of the machine, taking in account technical criteria and the costs to the project.
This work has the aim to present in a succinct way, what applied methodology, listing the criteria which were taken as relating to the choice.

PRODUCT DEVELOPING PHASES

The machine explained here is a product under development. Thus, it was made over three distinct phases requested during a product developing process [3]: pre-developing, developing and post-developing, as shown in Fig. 1.

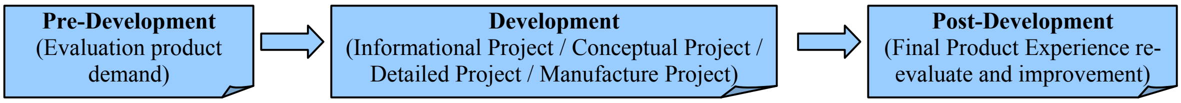

Figure 1: Product phases developing process.

Applying this procedure to the present study:

a) Pre-developing: This phase is account to PETROBRAS. Through its positioning into the market the company checked the need of a technology able to apply tests on high tonnage ropes and presented the technical specifications the machine should present.

b) Development: This phase is the aim of the work, and it has the necessary steps to the process for the whole machine development. The sub-phases that determined the best conception of the machine and are useful to the decision process machine were the following:

(b1) Informational Project**:** The developing of the product begins with its specification. This phase engage the information collecting about the requirements which must be set for the product, or machine as known;

- ✓ Sub ropes dimensions: 10m (total length), 2m (useful length) and 100 mm (diameter).
- ✓ Axial tension load: 300 ton and 150 ton.
- ✓ Working Pressure: 21 MPa.
- ✓ Machine able to execute rupture tension tests on 300 ton sub ropes.
- ✓ Machine able to execute fatigue tests on 150 ton sub ropes.

(b2) Conceptual Project**:** In this sub phase, the requirements or all the functional origins of the several machine systems are converted to a physical model (Fig. 2).

c) Post-Development: This phase gets worry about analyzing the final product and searching improvements and revitalization of the product.

THE CONCEPTUAL PROJECT

Here, it is definite the conception of the solution. The phases of the conceptual project are the following:

a) Identify essential problems; (Primary Functional Analyze)
b) Set up a structure of functions and sub-functions; (Secondary Functional Analyze)
c) Looking for ways of solutions to execute the sub-functions; (Morphological Matrix)
d) Combining the ways of solutions to execute the whole function; (Morphological Matrix)
e) Checking and selecting variants of the project; (Decision Table)
f) Initial Conception; (Comparative Result between Morphological Matrix and the Decision Matrix)

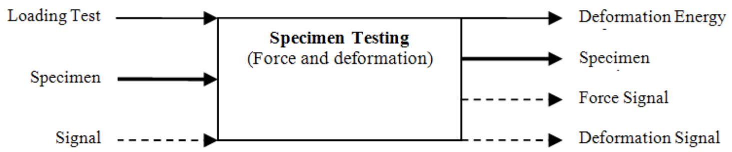

Figure 2: Functional scheme of the first level.

FUNCTIONAL ANALYZE

It is based on the functional requests the machine must present [2]. The product has its most complex working characteristic (global function) subdivided in less complex functions (sub functions). Thus, it facilitates the subsequent search for assembling solutions. The functional scheme of the first specific level to this work is represented in the block scheme of Fig. 2.

The functional scheme of the second level consist in subdivide the presented functions in the first level in its sub functions. Yet the functional schemes of the third level is based on the functional scheme of the second level, and divide all sub functions in their auxiliary ones, as shown in the scheme of the block (Fig 3).

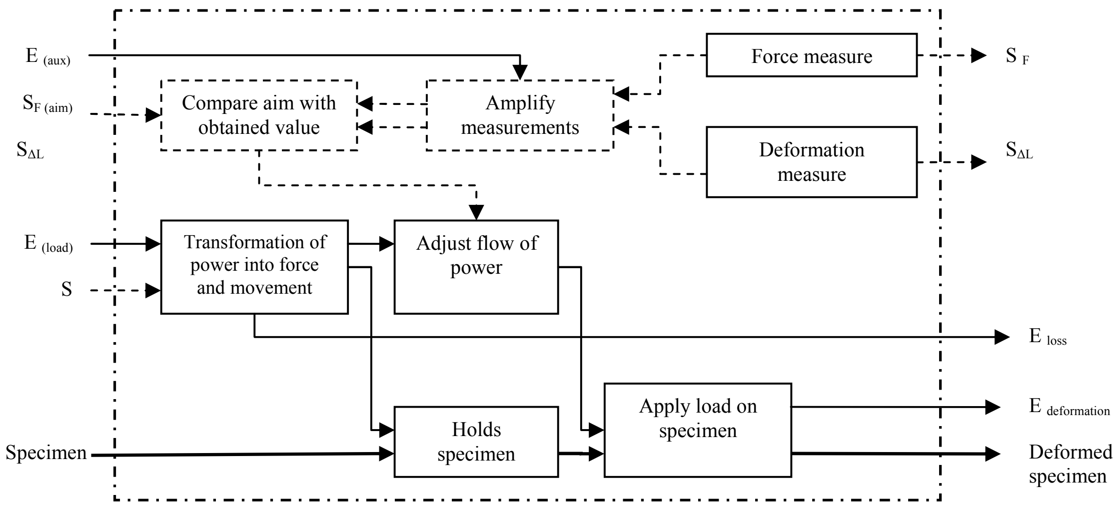

Figure 3 - Functional scheme of the third level

Arrow=Power flow and direction/**Bold Arrow**=Material and direction Flow/**Sketch Arrow**=Signals flows and Direction /**Full Box**=Main Functions/**Sketched Box**=Auxiliary Functions/**Sketched Line**=System Domain

MORPHOLOGICAL MATRIX

This is a structured method to generate alternative solutions for each sub function of the machine [3]. In this step, it is necessary to select the most viable or attractive option. The analyzes of the sub functions that have few alternatives to the solution or alternatives with fully stabilized technological characteristics must be excluded.

Tab. 1 shows the morphological matrix of this study. The cells in yellow show the best path found for the machine assembly. In fact, there is no dependence among alternatives to different functions; so, all combinations are possible. For example, S11 cell could be associated with S21 or S23 cells without harming the assembly, and the same could occur for the other combinations. Therefore, we have studied the solutions exclusively to the function regarding the load application to the specimen, which has high cost and high level of technology.

DECISION MATRIX

Considering the discussion in Section 3.2, the decision matrix was oriented to the cylinder alternatives to the machine. Thus, all three alternatives were evaluated according to important requirements related to technical and economic criteria.

Tab. 2 shows the decision matrix for this study [1]. The value of each attribute is related to its relative importance in the project. Each alternative is evaluated using grades from 0 to 10. The alternative B had the highest grade (8.1) that corresponds to two cylinder alternative. The alternative A (one cylinder under tension) and B (one cylinder under compression) got (7.2) and (7.0), respectively. We can observe that the highest grade of the alternative B in the manufacturing cost attribute was decisive to its high final grade.

FUNCTIONS	SOLUTIONS		
1) Transformation of power into force and movement	**S11 – Hydraulic** •There are options in the market for cylinders with the load range requested. •Several options in the market to assembly force and control systems. •Lower cost of the acquisition and maintenance.	**S12 – Electric** •Discarded by the high cost associate to consume of electrical power. required to operate the machine. •Non comercial project required.	**S13 – Pneumatic** •There are not at the market cylinders with the range of load requested to apply the tests.
2)Holding the specimen	**S21 – Pin** •Simplicity of design and lower manufacture cost. •The perfect embrace of sub rope on the pin is harmed by its constructive characteristics, causing forces that contribute to wear and even break sub rope on this contact area.	**S22 – Roller** •Constructive characteristics favorable to the full embrace of the cable on the roller. • There are lower chances to show deformation forces or rupture of the sub rope on the contact area.	**S23 – Hook** •Easy handle and simple design. •Loads required an robust piece. • The perfect embrace of sub rope on the hook is harmed by its constructive characteristics, causing forces that contribute to wear and even break sub rope on this contact area.
3) Applying load on the specimen	**S31 – One cylinder under tension (performing fatigue and rupture tests)** •High acquisition cost of the cylinder and the aggregate system (≈5x more expensive). •Support structure simplified. •Assembly simplified operations. •Reduced physical space is required.	**S32 – Two cylinders under tension (fatigue and rupture tests performed individually)** •Flexibility of the system, i.e. in case of arrest of one of the cylinder, the other one is able to the test. •Reduced cost, because the cylinder and the aggregate system responsible for the fatigue test may have a smaller capacity, and then reducing the cost of equipment. •Assembly and complex operations. •More complex accessories for fastening the cylinder structure. •Optimization favored. Both cylinders could be exchanged.	**S33 – One cylinder under compression (performing fatigue and rupture tests)** •For the same cylinder, the capacity to compression is greater than when it is used under tension. •High demand for physical space. •High manufacture cost. •Possibility of misalignment.
4) Measuring the deformation	**S41 – Displacement magneto resistive sensor** •Easy assembly. •Low acquisition cost •Previous experience in testing systems with cables proves the quality of the equipment in data acquisition.	**S42 – Infrared sensor** •Complicated assembly. •Without protection against humidity. •Difficulty of operation.	**S43 – LVDT** •Required constant calibration •Good resolution and high sensitivity •Equipment expensive •High cost to treat the signal.

Table 1: Morphological Matrix.

ATTRIBUTES	WEIGHT (W)	ALTERNATIVE A (one cylinder under tension)		ALTERNATIVE B (two cylinders under tension)		ALTERNATIVE C (one cylinder under compression)	
		GRADE (G)	W x G	GRADE (G)	W x G	GRADE (G)	W x G
Safety	0.15	10	1.5	10	1.5	10	1.5
Manufacture Cost	0.4	4	1.6	8	3.2	5	2
Reliability	0.05	10	0.5	8	0.4	10	0.5
Performance	0.1	10	1	10	1	10	1
Maintenance	0.05	9	0.45	7	0.35	8	0.4
Assembly	0.08	9	0.72	6	0.48	6	0.48
Durability	0.02	4	0.08	8	0.16	4	0.08
Operates	0.08	9	0.72	7	0.56	9	0.72
Physical Space	0.07	9	0.63	7	0.49	5	0.35
SUM (Σ)	1		Σ = 7.2		Σ = 8.1		Σ = 7.0

Table 2: Decision Matrix.

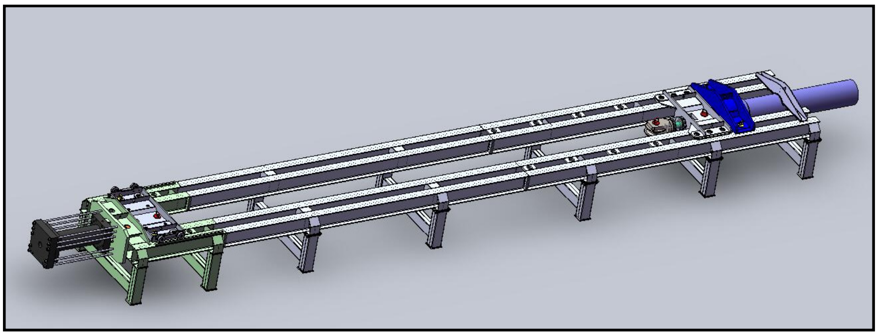

Figure 4: Scheme of the machine.

Conclusion

This paper presented the application of a decision methodology to a test machine in order to evaluate the tension and the fatigue of the sub ropes. This machine has been developed at POLICAB with PETROBRAS. We emphasized the conceptual project phase which is one of the product development phases. The functional analyzes and the elaboration of the morphological and decision matrices are detailed.
The function regarding of the application of load to the specimen was evaluated and its project variables were selected. Three alternatives were proposed, and the two cylinder on tension option was chosen; one of the cylinders is responsible for the tension test and the other one, for the fatigue test. In the future, we are going to analyze the development of the product phase, related to the detailed machine design and the machine manufacture.

Acknowledgement

The authors want to thank *PETROBRAS – Petróleo Brasileiro S.A.* for its support to research, POLICAB- Stress Analysis Laboratory for the opportunity to the develop scientific knowledge and special thanks to Prof. Dr. Paulo Teixeira for his support and impeccable contribution to this paper.

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