Proposed new bending stiffener for flexible pipes

Author Names: Luciano Valdomiro dos Santos / Edison Gonçalves
Petropasy Polyurethane Technology
Department of Mechatronics Engineering and Mechanical Systems (Polytechnic School, University of São Paulo)
São Paulo, São Paulo, Brazil

ABSTRACT

This paper presents a new bending stiffener for flexible pipes, a metal-polymer structure used by the oil and gas industry, which has stress concentration values in the anchoring of the polymeric part (polyurethane) with the metal part (insert) lower than the current traditional bending stiffener. Initially, it presents bending stiffeners. Then shows the characteristics of the current traditional bending stiffener and, finally, presents the new bending stiffener.

Keywords: bending stiffeners; flexible pipe; stress concentration.

INTRODUCTION

The bending stiffeners are structures composed of a polymeric part, usually made from thermoset polyether polyurethane [LEMOS 2005] anchored to a metallic part which is intended to allow the installation of the assembly in the place of use. They are responsible for the smooth transition of stiffness between a very flexible structure flexible line (riser or umbilical), and one which is extremely rigid that is structure of an oil platform (figure 1).

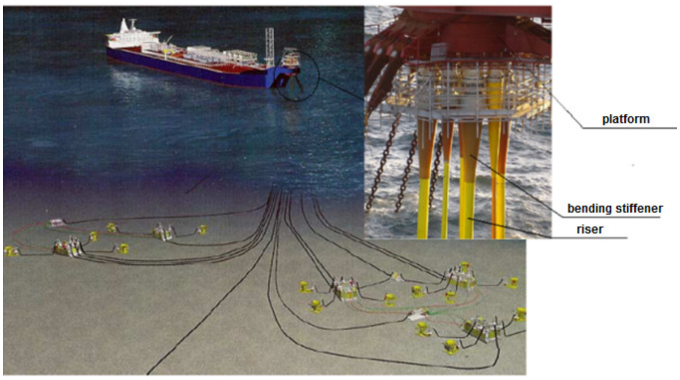

Figure 1 - Bending stiffener, FPSO platform and risers, [CAIRE, 2005].

The flexible pipes have been increasingly used in applications for offshore oil exploration in recent years. They are used to transport various types of fluids, usually at high pressure. They have several metal layers combined with concentric polymeric layers to form a structure with high torsional and axial rigidity, but a low flexural rigidity, [LEMOS, 2005].

Figure 2 – Flexible pipe, [LEMOS, 2005].

The bending stiffeners appeared due the need to avoid very small radii of curvature that can damage the structure of the flexible lines used in offshore oil exploration. The correct evaluation of bending stiffeners can mean the difference between safe operation of a flexible line or from your failure, especially in the case of units of FPSO platforms (Floating Production, Storage and Offloading) or more critically in single point mooring [LEMOS, 2005]. The monobuoys, especially in deep water, can lead to extreme situations flexible pipes that besides suffering from high tensile loads, they are subject to high bending stresses imposed by monobuoy movements. This has aroused great concern in the oil companies, in particular, at Petrobras, especially after the failures recorded in the Campos Basin in 1998 and 1999, when the bending stiffeners of monobuoy IMODCO III in the Marlim field, after six months of operation, suffered failure [POPE, 1998]. A lot of bending stiffeners of the same project continue in operation in some FPSOs causing concern over its useful life, [CAIRE, 2005]. The failure analysis of bending stiffeners led to the conclusion that the predominant failure mechanism was initiated by the polymer fatigue, [POPE, 1998].

CURRENT TRADITIONAL BENDING STIFFENER

The bending stiffeners are composed of a polymeric part anchored to a metallic insert (see Figure 3).

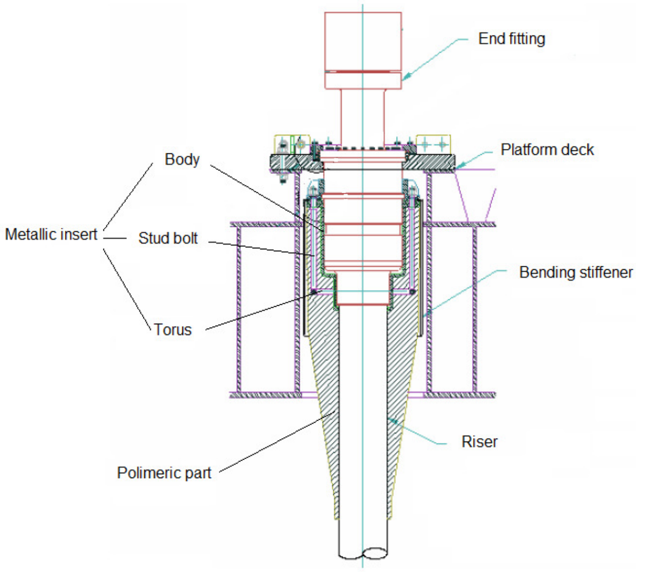

Figure 3 – Traditional Bending Stiffener, [CLEVELARIO].

The metallic insert is essentially composed of a stepped welded metal body and a toroidal ring welded to stud bolts, which are perpendicularly arranged axially in relation to said toroidal ring and the flange of the metal body (see figure 4). This configuration forms a type of cage that surrounds the circumference of the flexible pipe. Thus when the polymeric part of the bending stiffener is subjected to external bending, the insert keeps anchored the base of the bending stiffener. The cage configuration is ideal for ensuring the anchoring of the polymeric part. The main problems of metallic insert are:

- Impossibility to design infinite life, even under ideal conditions;
- Necessity of execution of various nondestructive testing for the verification of welded joints;
- Presence of discontinuities in welds inherent to the process;
- Difficulty to ensure the roughness of the interface areas with the polymeric part by the fact that it is obtained by manual grinding and polishing.

Due to these problems, the use of expensive super alloy (inconel 625, for example) is required for the construction of the metallic insert.

Table 1 shows the relevant properties of each material used in the construction of bending stiffeners. Note that the cost of Inconel 625 is twenty-five times greater than that of structural steel USI SAC 350.

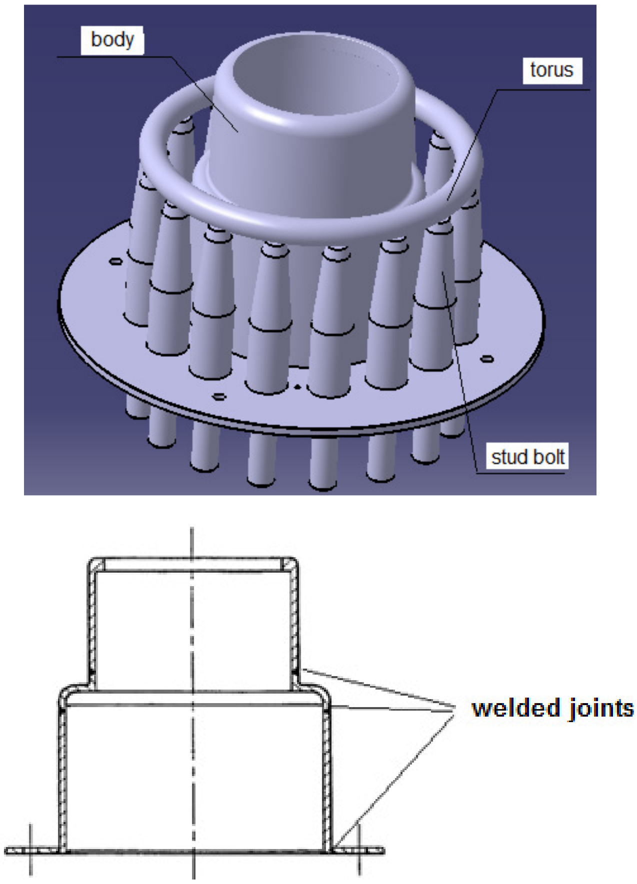

Figure 4 – Traditional metallic insert welded, [SANTOS, 2014].

Table 1 - Properties of materials used in bending stiffener, [SANTOS, 2014].

Bendig Stiffener parts		Insert body	Insert stud bolt and torus	Polimeric part
Property		USI SAC 350	Inconel 625 annealed	Thermoplastic polyurethane polyether
Carbon [%]		Máx. 0,25	Máx. 0,10	
Manganese [%]		Máx. 1,5	Máx. 0,50	
Sulfur [%]		Máx. 0,02	Máx. 0,015	
Phosphorus [%]		0,01 a 0,06	Máx. 0,015	
Silicon [%]		0,5 a 1,50	Máx. 0,50	
Chrome [%]		Máx. 0,60	20 a 23	
Molybdenum [%]			8 a 10	
Nickel [%]			Mín. 58	
Iron [%]			Máx. 5,0	
Niobium [%]			3,15 a 4,15	
Copper [%]		0,05 a 0,4		
Modulus of elasticity [GPa]		190 a 210	208	0,045
Poisson's Ratio		0,27 a 0,30	0,28	
Tensile strength [MPa]		500 a 650	827 a 1034	42
Yield strength [MPa]		Mín. 350	415 a 655	
Elongation [%]		Mín. 16	30 a 60	325
Average Impact Resistance [J]			66 (29°C) / 57 (-79°C)	
Fatigue strength [MPa]	10^4 cycles			
	$4x10^4$ cycles			
	10^5 cycles			
	$4x10^5$ cycles			
	10^6 cycles		655	
	$4x10^6$ cycles			
	10^7 cycles		630	
	10^8 cycles		621	
Cost [USD/kg]		4,00	100,00	

The manufacture of the bending stiffener is a complex process. Essentially the operation entails the construction of a mold tool. A center tube is positioned within an outer shell forming a cavity the shape of the required component. The metallic insert is placed in the base unit bottom sealing tool as shown in Figure 5. The metallic body of the insert is coated with a suitable adhesive. The toroidal ring and the stud bolts of the metallic insert, together with the inner surfaces of the tool are treated with a release agent prior to assembly. Prior to filling, the mold is heated to a suitable temperature. The polyurethane is then fed through a filling hole usually located at the bottom of the mold. The liquid rises, displacing air from the cavity through a hole, which is usually located at the highest point of the assembly. When the filling operation is completed, the initial curing of the material takes place with the reaction and solidification of polyurethane. The solidified component is then demolded and subjected to detailed inspection before being approved. This manufacturing process is designed to ensure perfect adhesion between the polyurethane and the body of the insert, and a slip between the polyurethane and the torus insert.

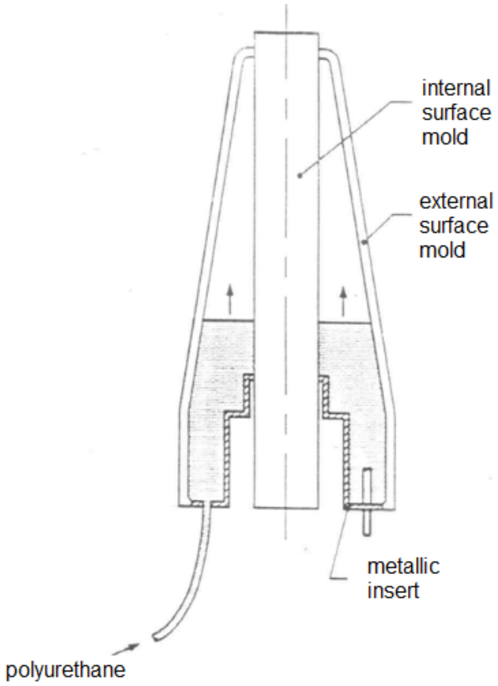

Figure 5 – Mold for bending stiffener, [KIEPPER, 2004].

The main potential defects of the traditional bending stiffeners are [API 1999]:

- Cracking of polymeric part;
- Breaking of the polymeric part;
- Structural failure of the insert;
- Performance loss of the polymeric part.

One possible cause for the first three defects is the fatigue mechanism [API 1999]. The main points of failure due to fatigue are shown in figure 6, [DEMANZE, 2005].

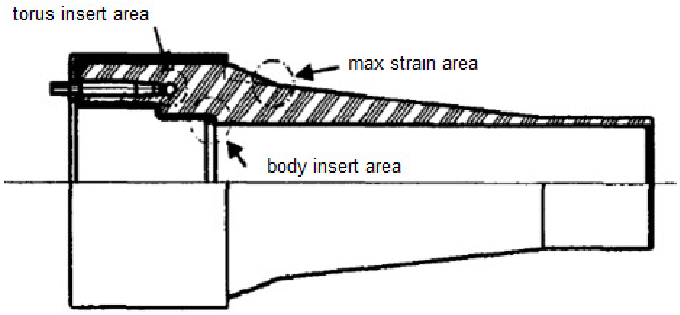

Figure 6 – Critical areas to fatigue failure, [DEMANZE, 2005].

It is noticed that two critical regions are located at the interface of the polymeric part with the metallic part of the bending stiffener, that is, the anchorage area, where cracks are most likely nucleated due to failure by sliding, which is strongly influenced by surface roughness, [HUTCHINGS, 1992].

NEW BENDING STIFFENER

In order to solve the existing problems in the traditional bending stiffeners, it proposed a new bending stiffener that uses a modular insert for anchoring the polymeric part, which presents a new constructive arrangement, because it continue to present cage structure but is completely free of structural welded joints between it modular elements (see figure 7). For this purpose, this form of construction provides the fitting between modular bodies, resulting in a structure (insert itself) unified composed of several individual portions locked each other. The portions or individual component parts of the insert are locked to each other by threading the stud bolts in the supporting flange (optionally, the locking can be performed by applying a non-structural weld between the stud bolts and the supporting flange, once the way the bending stiffener is installed ensures the locking of the insert modules). The main advantages of the new stiffener bending are:

- the insert does not use any structural welding allowing the choice of common structural materials, ferrous or non-ferrous;
- under ideal conditions, it is possible to design the insert for infinite life;
- better roughness in the interface areas between the polymeric and the metallic part;
- the modular insert has average cost 50% lower than the traditional welded insert.

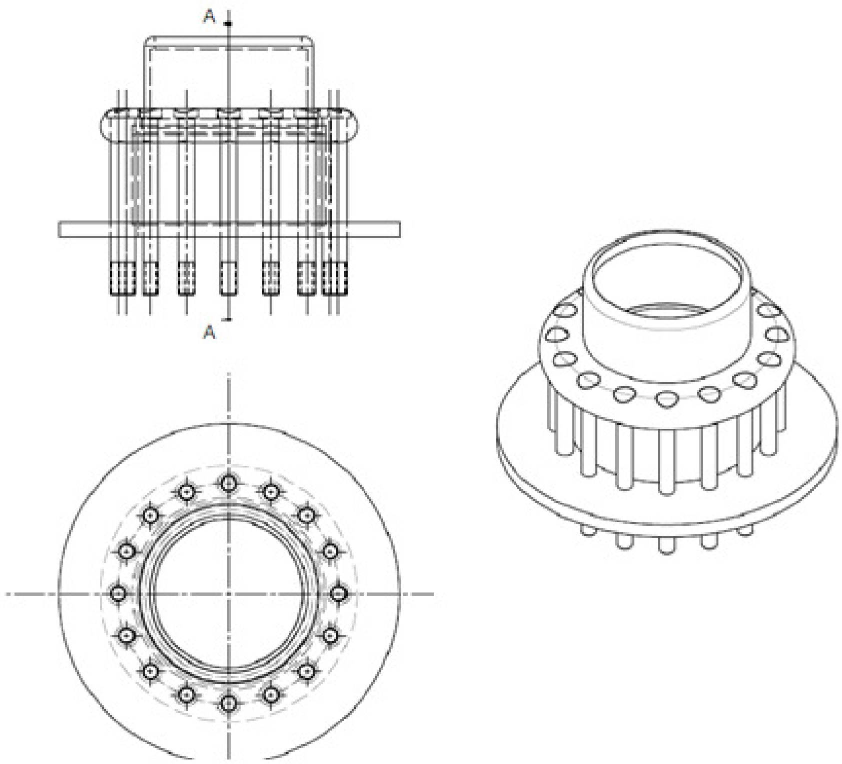

Figure 7 – Modular insert

Also, the manufacturing time of the new bending stiffener is much smaller than of the traditional bending stiffener due to the fact that the modular insert present approximately 60% less operations compared to traditional insert as shown in Table 2.

The modular insert shows stress levels below those present in the traditional insert. This is due to the absence of joints with structural welding and due to the fact that their stud bolts only receives part of the compression load. Therefore, for the same design, the stud bolts of this insert are subjected to lower alternating stress than the traditional insert. This increases the safety factor of these stud bolts and allows the possibility of decreasing the size of it or the use of less resistant materials.

The sliding failure of the polymeric portion of the new bending stiffener may be minimized due to the better control of the surface roughness of the insert, thus avoiding nucleation of cracks in the interface regions.

It was realized two analyzes by finite elements method, one in a traditional bending stiffener and another in the new bending stiffener to check the influence of the geometry of the inserts in tension generated in the anchorage area, using the same external dimensions, boundary and loading conditions. Figures 8 and 9 show the results.

Table 2 - Comparative number of operations between traditional and modular inserts.

	Operations	
N°	**Traditional insert**	**Modular insert**
1	Preparation for welding	Machining of the parts
2	Welding of pipes and plates	Inspection of the parts
3	Ultrasound test	Assembly
4	Stress relief	Deburring
5	Machining of the body	Final inspection
6	Liquid penetrant test in the body	
7	Inspections of the body	
8	Welding of the torus and stud bolts in the body	
9	Grinding	
10	Liquid penetrant test in the gage	
11	Polish	
12	Final inspection	
	12 operations	**5 operations**

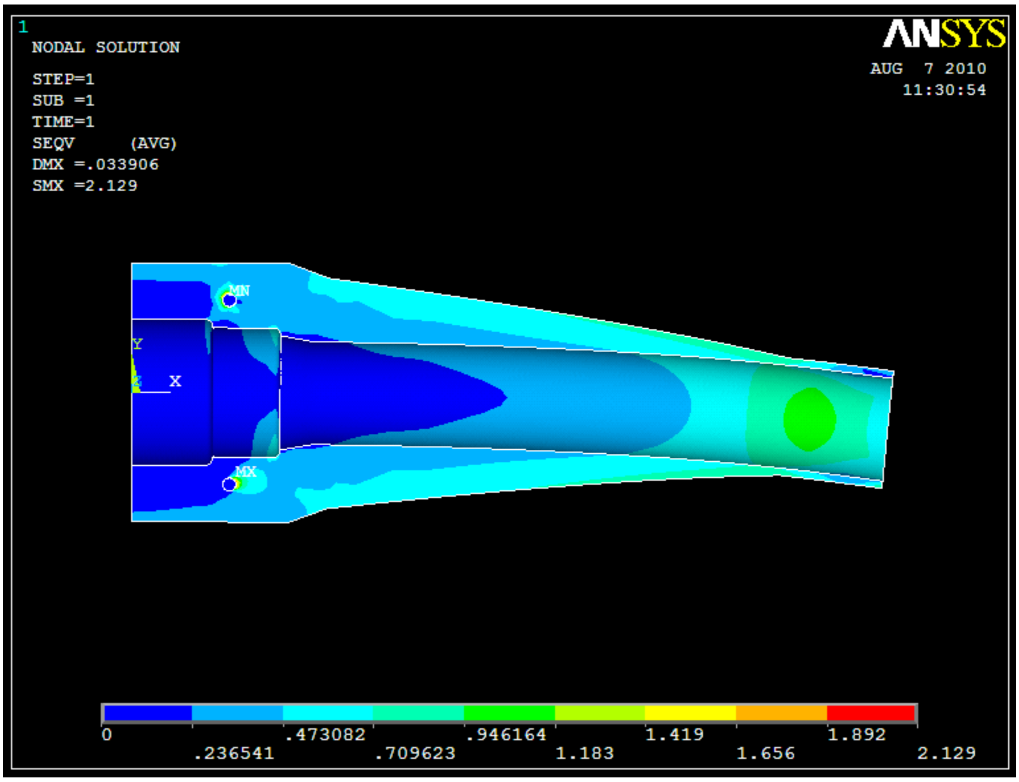

Figure 8 – Traditional bending stiffener.

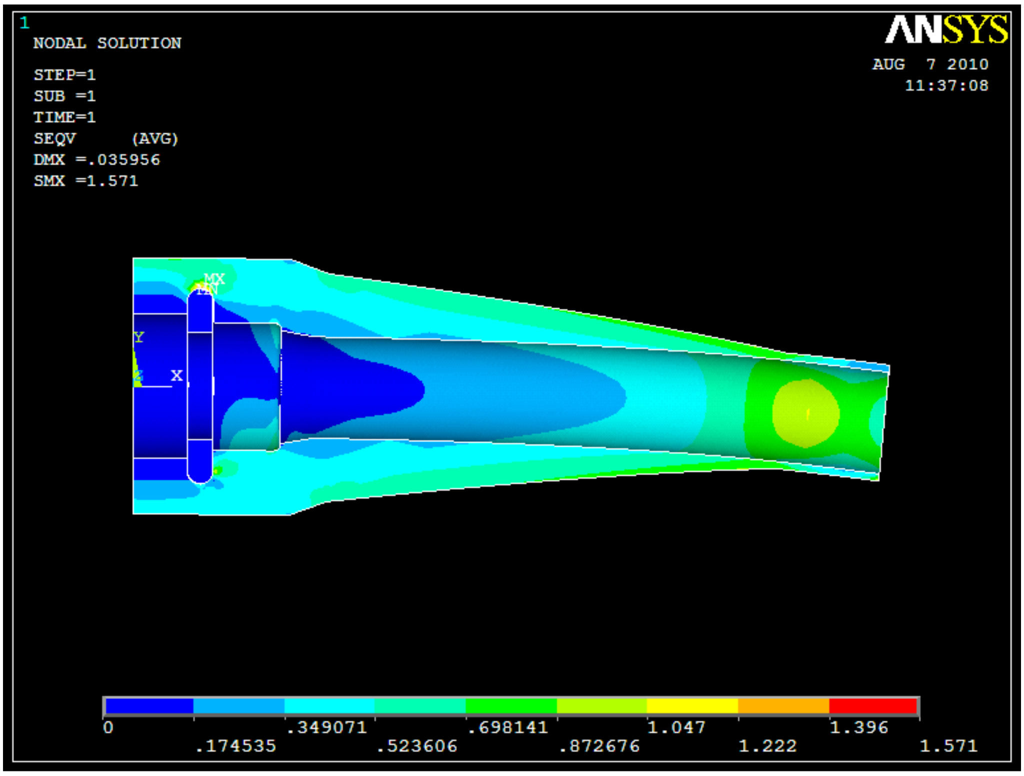

Figure 9 – New bending stiffener.

It was noted that the traditional bending stiffener showed a maximum Von Mises stress of 2,129 MPa. Already the new bending stiffener showed a maximum Von Mises stress of 1.571 MPa. Thus, we concluded in this case that the modular insert reduced by approx. 25% the stress concentration in the polymeric part compared to traditional metal insert.

CONCLUSIONS

The main conclusion of this work is that the geometry of the insert has a fundamental performance in reducing stress levels present in the polymeric part of the bending stiffener. It was proven the possibility of designing a new bending stiffener more reliable than the traditional bending stiffener by the fact that: do not use any structural welding thus enabling the choice of common structural materials, ferrous and non-ferrous; enabling, under ideal conditions, a design to infinite life; enable better roughness`s assurance of the insert interface areas with the polymeric part.

REFERENCES

API Recommended Practice 17B Recommend Practice For Flexible Pipe. AMERICAN PETROLEUM INSTITUTE, 1999.

CAIRE, M. Bending Stiffeners Analysis. 2005. 115 f. Dissertation (Master of Science), COPPE/UFRJ, Rio de Janeiro, RJ, Brazil, 2005.

CLEVELARIO, J. Introduction to Unbonded Flexible Pipe Design and Manufacturing. USP Course on Flexible Pipes.

DEMANZE, F. et al. Fatigue Life Analysis of Polyurethane Bending Stiffeners. Proceedings of 24th International Conference on Offshore Mechanics and Arctic Engineering. OMAE 2005-67506, Halkidiky, Greece, June 2005.

KIEPPER, B.O. Structural Static Analysis, by Finite Element of the Riser-Bending Stiffener segment. 2004. 95 f. Dissertation (Master of Science), COPPE/UFRJ, Rio de Janeiro, RJ, Brazil, 2004.

LEMOS, C. A. D. Fatigue Analysis in Risers. 2005. 248 f. Thesis (Doctor of Science) - COPPE/UFRJ, Rio de Janeiro, RJ, Brazil, 2005.

POPE, A. M.; CARDOSO, L. G. C.; SANTOS, J. M. Failure Analysis of Bending Stiffener of IMODCO III monobuoy. Internal technical communication Petrobras No 127/08; CENPES/SUSEP/DIPLOT/SEMEC. October 1998.

SANTOS, L.V. Failure analysis of metal-polymer structures: bending stiffeners. 2014. 129 f. Thesis (Doctorate in Mechanical Engineering) - POLI/USP, São Paulo, SP, Brazil, 2014.