INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON		EDF
Departement **G**énie **M**écanique **D**éveloppement	**Training placement - short report**	**Electricité de France** SEPTEN Rotating Machine Group
Training period: From the 2014/06/23 until the 2014/12/19	Student: **Silun ZHANG**	Person in charge at the company: **Pierre-Yves COUZON** Senior Engineer

Instructions:

1 – The whole document has to be written in ENGLISH, using the font Arial (12 pts) with a 1pt interline.

*2 - The aim of this short report will be to give an overview of your engineering approach during your training placement. Your report will follow a strict outline, with the same objectives and constraints as for a scientific paper (please see below). Furthermore****, this report will NOT be confidential****; it is therefore your responsibility to adapt the data in consequence (by using dimensionless graphs/figures for example). Access to the report will be restricted to both students and teachers of GMD.*

Title: (2 lines maximum)

Updating of numerical models of hydrodynamic bearings and analysis of their influences on the dynamic behavior of a turbine generator shaft line

Abstract: (15 lines maximum)

This short report summaries the main steps and the key conclusions of my tasks during the graduation internships at EDF. These tasks focus on the rotor dynamic analysis of the main turbine generator shaft line of nuclear power plants P4 1300MW.

The purposes of the internship are to update the old numerical models of the shaft line, previously created by EDF, and to analyze the impact of the revisions on the dynamic behavior. Existing numerical models showed smattering flaws which have to be improved. In parallel, with the updated version of computing tool EDYOS(Calculation of the behavior of hydrodynamic bearings), the model of bearing integrates better the physic behavior of bearings by taking into account the ‘flexibility of pivot’ in hydrodynamic bearing model, The results show their significant influences on the value of dynamic coefficients. Since these coefficients are used as boundary condition in numerical models of shaft line, the study also concludes about their impacts of the on the dynamic behavior of the shaft line.

Key words: Turbine generator set, Shaft line, Nuclear power plant, dynamical coefficient, hydrodynamic bearing, rotor dynamics

Presentation of the company: (1/2 page including figures)

EDF SEPTEN is one of the six EDF's nuclear engineering departments. The company is located in Villeurbanne in the Rhône department since 1984. Its general function is to set the doctrine of nuclear facility and of equipment design such as regulation assessment, control principles and rules and technical specifications. It provides demonstrations of the safety of these facilities and equipments from their design to the end of their utilization. EDF SEPTEN employs over 600 staff. It has 9 divisions and each specializes in different technical areas.

The division of engineering where I did my internship at EDF SEPTEN is IT which is composed of 36 agents and is divided into three groups: MT (rotating machine group); SF (cold source group) and SM (machine room group). Its main activities are in the areas of system design, installation of power generation, cold source and rotating machines.

The engineering study that I handled during the internship is integrated to the mission of the MT group. The MT group deals with study and qualification of rotating machines such as primary pump station, pumps of the safeguard systems, main and auxiliary steam turbines.

Context of the project: (1/2 page including figures)

The internship concerns the dynamic analysis of the shaft line in nuclear power plants P4-P'4 1300MW. The shaft line, which is also known as turbine generator set, is composed of four turbines and one generator rotors. This rotating machine transforms the thermodynamic energy of steam into mechanical energy on the rotors. Then, these rotors couples with the generator to generate electricity.

During this internship, I worked on the dynamic analysis of both the shaft line and the hydrodynamic bearings. The bearings support and guide the shaft line. They are in contact with the rotors and have therefore a direct influence on their dynamic behaviors.

EDF has already built numerical models to perform calculations of bearings. However, these older models could be further improved by integrating some physical hypothesizes which were not considered at that time because of underdeveloped EDYOS code version. Thanks to a breakthrough in computing tool EDYOS, the integration of the calculation hypothesis 'flexibility of pivot' becomes possible. This integration leads to the updating of bearings numerical models. An analysis of the impact is followed after the model update.

In addition, as the origins of some data cannot be explained or even erroneous, this internship aimed at updating the model of the 1300WM shaft line as well.

Once the shaft line model is updated, calculations based on the updated coefficients of hydrodynamic bearings are performed in order to check their impacts on the dynamic behavior of the shaft line.

Thus, the objectives of the internship are:

- Updating the numerical models of the bearings by integrating the flexibility of pivots.
- Updating the model of the shaft line.
- Perform analysis on the dynamic behavior of the shaft line with the updated model and updated coefficients of bearings.

Methodology: (1 to 2 pages including figures)

- **Introduction of the final objective of this study**

The final objective of this study is to update the numerical models of the shaft line of the main turbine generator set of 1300 MW nuclear power plants, in order to predict more accurately its dynamic behavior. In fact, the calculated modes of shaft line could be changed by renewing the numerical models of bearings and shaft line. The recalculated modes will approach more the reality as updated models are more precise. Thus, calculation results after this renewal predict more accurately the dynamic behavior of the shaft line and avoid possible risk.

- **Updating of the numerical models of bearings**

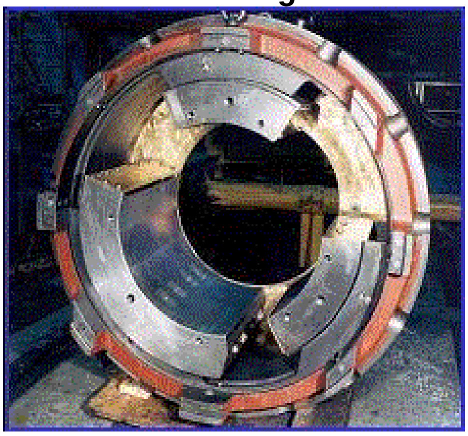

Figure 1 a hydrodynamic bearing

Hydrodynamic bearings numerical models are designed from tilting pad bearings. The type of hydrodynamic bearing used to support the 1300MW shaft line consists of 3 pads: carrier pad, upper pad and side pad. Below these pads, a pivot connects each pad to the support. The upper pad is mounted on a flexible substrate composed of pre-stressed washers to ensure that there is no floating of the upper pad at low rotation speed.

The role of hydrodynamic bearings is to support and to guide the shaft line which is about 1000 tons. The lifting force on the shaft line during its normal running can be present by stiffness and strain of pre-stressed washers, pivots and oil film. Thus, bearing is modeled by the stiffness of its components though a computing tool EDYOS.

In the former bearing numerical models, the strain of pivots was not considered inside the EDYOS model. For the new model of bearings, EDYOS is developed and integrated strain of pivots which is called also flexibility of pivots. In the *Figure 2*, one can distinguish more intuitively the differences between both versions.

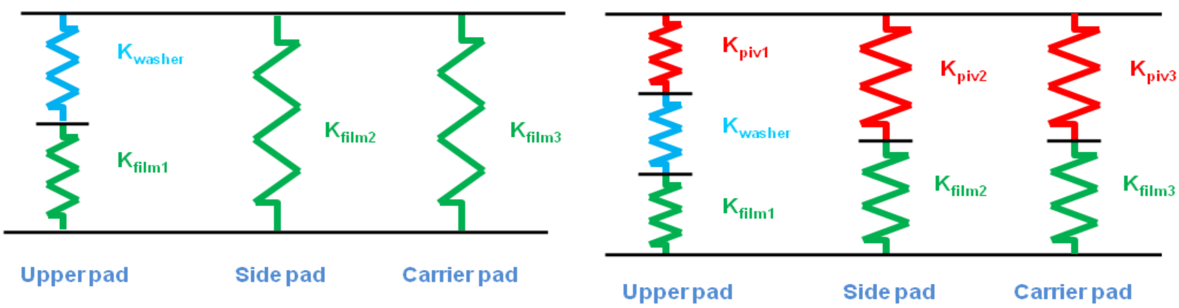

Figure 2 Two EDYOS numerical models of bearing

All stiffness can be evaluated with the confidential technical data at EDF which allows us to update the numerical models of the bearings. Calculation of the bearing dynamical coefficients for each bearing will be based on these updated models. Then, these coefficients will be individually integrated into the model of the shaft line.

The update of bearings models proves the stiffness and damping coefficients evolution. Therefore, an analysis on the impact of the integration of the flexibility of pivot on dynamic coefficients is done on models with and without pivots.

- **Updating of the model of the shaft line**

The shaft line of GTA P4-P'4 1300MW consists of a high pressure turbine (HP), three low-pressure turbines (LP) and an alternator (ALT). Seven hydrodynamic bearings are supporting this shaft line and are illustrated by yellow triangles in the *Figure 3*.

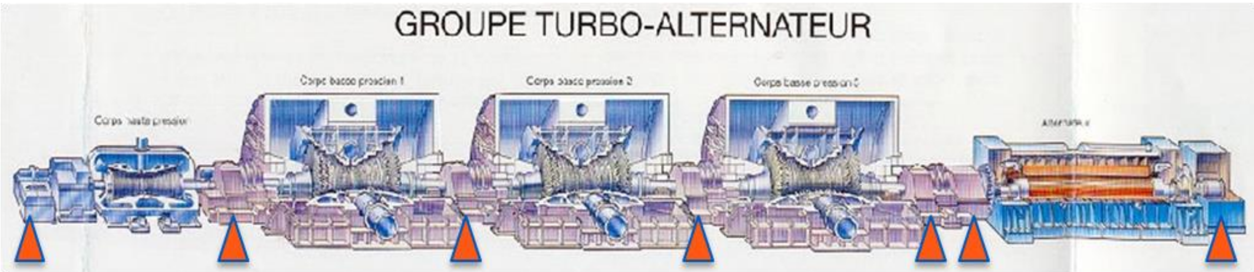

Figure 3 the 1300WM P4 turbine generator shaft line

This numerical model was designed in Salome-meca. Some data's sources cannot be explained and are incoherent with the data of the manufacturer. The update makes the models more accurate.

During the internship, the update was done by referring to the production drawings.

Once the model update according to the plans is done, a process aimed to the validation of model is taken. This validation process consists of three steps:

- Checking of the general characteristics (geometry, mass and moments of inertia).
- Checking of bearings reaction forces and displacement under own weight.
- Checking of natural modes at 1500 rpm.

These verifications were conducted by comparing the reference values (taken from the manufacturer studies) with those of updated model and no-updated model. The small differences between the compared values validate the updating of the shaft line model.

- **Reevaluation of the dynamic behavior of the shaft line.**

Once the models updated are done and validated (bearings and shaft line), both can be used to re-evaluate the dynamic behavior of the shaft line. This analysis realizes the ultimate objective of study.

During this internship, modal calculations were performed using the updated models of the shaft line. In order to analysis the influence of integration of flexibility of pivots, updated coefficients of bearings and original coefficients have been both used. Both results of modal calculations were presented in the Campbell diagram and were compared to emphasize the impacts of the integration of the flexibility of the pivot on the numerical model.

Results: (2 to 3 pages including figures)

- **Analysis of impacts of integrating pivots' flexibility on the dynamical coefficients of bearings.**

Two types of results were remarked among all the results after the integration of flexible pivots: Those of the turbines and those of the generator. The comparison is made between the results with and without the effect of the flexible pivots.

- **The results of the bearings of turbines.**

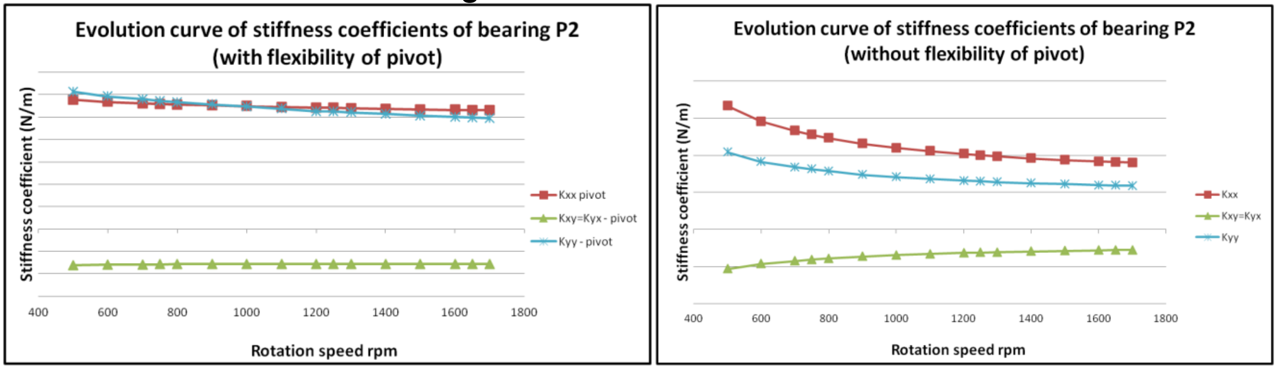

Figure 4 Comparison of evolution curve of stiffness of two models

P2		500 rpm	750 rpm	1000 rpm	1250 rpm	1500 rpm	1700 rpm
Version		Ratio with/without (flexible pivot)	Ratio with/without (flexible pivot)	Ratio with/without (flexible pivot)	Ratio with/without (flexible pivot)	Ratio with/without (flexible pivot)	Ratio with/without (flexible pivot)
Stiffness coefficient (N/m)	Kxx	411%	331%	293%	272%	254%	246%
	Kxy	461%	364%	313%	285%	269%	257%
	Kyx	461%	364%	313%	284%	269%	257%
	Kyy	257%	220%	203%	197%	193%	190%
Damping coefficient (N.s/m)	Cxx	2243%	1556%	1291%	1151%	1014%	968%
	Cxy	3175%	2055%	1617%	1406%	1437%	1409%
	Cyx	3158%	2035%	1593%	1377%	1380%	1335%
	Cyy	797%	603%	524%	484%	454%	440%

Table 1 Comparison of dynamical coefficients of two numerical models

The results of the comparison show that the integration of flexible pivots actually has a significant impact on the coefficients of bearings. We can withdraw the comments from the *table 1 and Figure 4* above for the turbines:

- The values of the stiffness coefficients without the effect of the pivot flexibility are between 5 and 2 times bigger than with the pivot.
- The damping coefficients are more sensible in comparing with stiffness coefficients.
- The coefficients of bearings are more constant (versus the rotation speed) with the effect of the flexibility of the pivot.

- **The results of the bearings of the generator**

The results of the alternator bearings are however different from those of the turbines. A phenomenon of the sudden change was noticed. *See figure 5*.

This sudden change in dynamic coefficients comes from the characteristics of the upper pad. After the integration of the flexibility of pivot in the modeling, the upper pad reacts according to a complex stiffness law (*see Figure 6*). When the hydrodynamic effort is below the preload force F0, the behavior follows the stiffness law of the oil film; the strain of the upper pad is zero. By increasing the speed of rotation, the force reaches the value of preload force F0; the pre-stressed washers are suddenly working. Since the washers' stiffness is 1000 times weaker than the oil film stiffness, their contributions are more marked in the behavior of the upper bearing. The difference between these two stiffness values is so huge that the coefficients of oil film evolve tremendously.

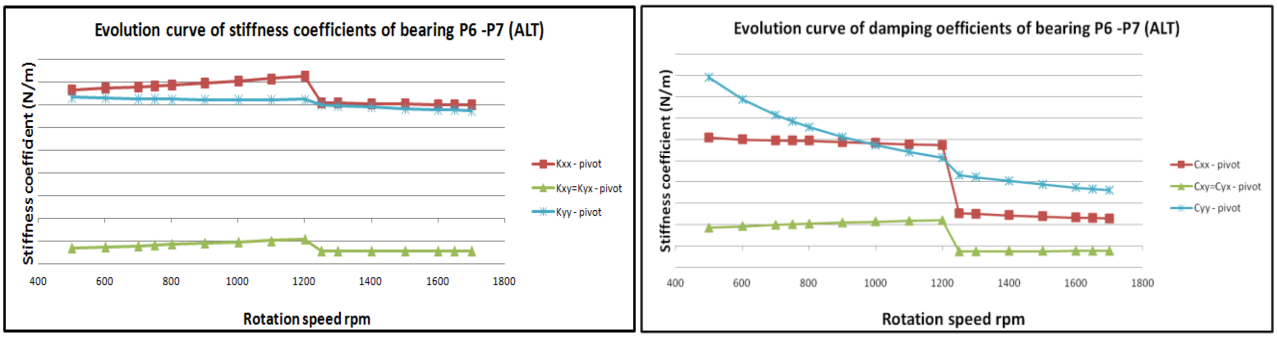

Figure 5 Evolution curve of dynamical coefficient of generator bearing (ALT)

In the case of generator bearings, after analyzing the calculation sheets, we found below 1250 rpm, the hydrodynamic force applied to the upper pad is less than preload force F0. Above 1250 rpm, the washers start to be crushed and the hydrodynamic forces are within the operating range of the washers. The sudden change of coefficients of Oil Film comes thus from these stiffness changes between washers and oil film.

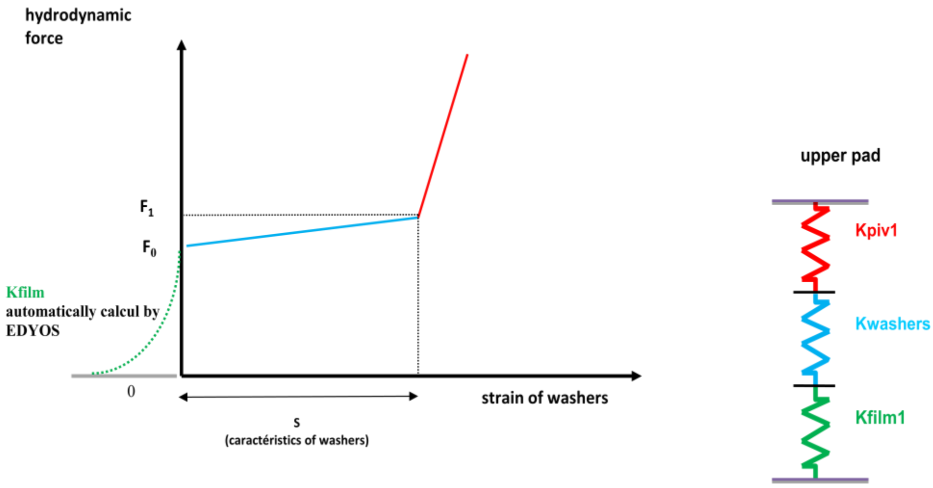

Figure 6 Stiffness law of upper pad

- **Validation of the shaft line model.**

The results of the updated shaft line model are reflected in process of validation. The calculated values are compared with reference values of manufacturer ALSTOM. The results of HP rotor shown in *the table 2* are chosen to represent the overall results. The results of the static calculations and modal calculations at 1500 rpm are not presented in this report.

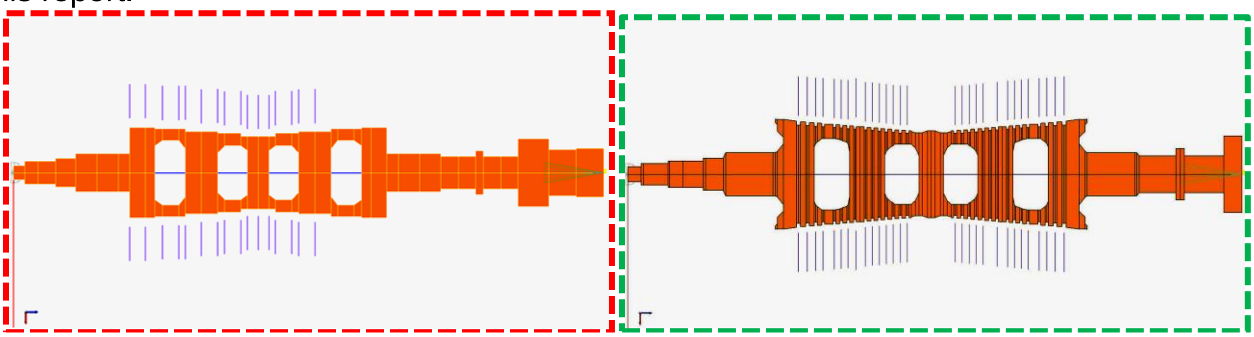

Figure 7 Comparison of updated model with original model (turbine High pressure)

Model	Différence updated/reference	Différence ancient/reference
total length (mm)	0,08%	5,03%
Total weight (kg)	0,00%	7,94%
Location of center of gravity(mm)	0,96%	2,75%
total inertia (kg.m2)	0,29%	41,81%

Table 2 comparison of two models with reference model

Through the comparison tables, a decrease of differences between the updated model and the reference model can be noticed, which validates the updated model.

- **Analysis of the dynamic behavior of the shaft line with the updated models**

The analysis results of the dynamic behavior of the shaft line 1300WM are presented in the Campbell diagram *in the figure 8*. We present here only the results and the remarks with the flexibility of the pivot. The values are treated in dimensionless values.

  - Modal calculation with the effect of the flexibility of the pivot.

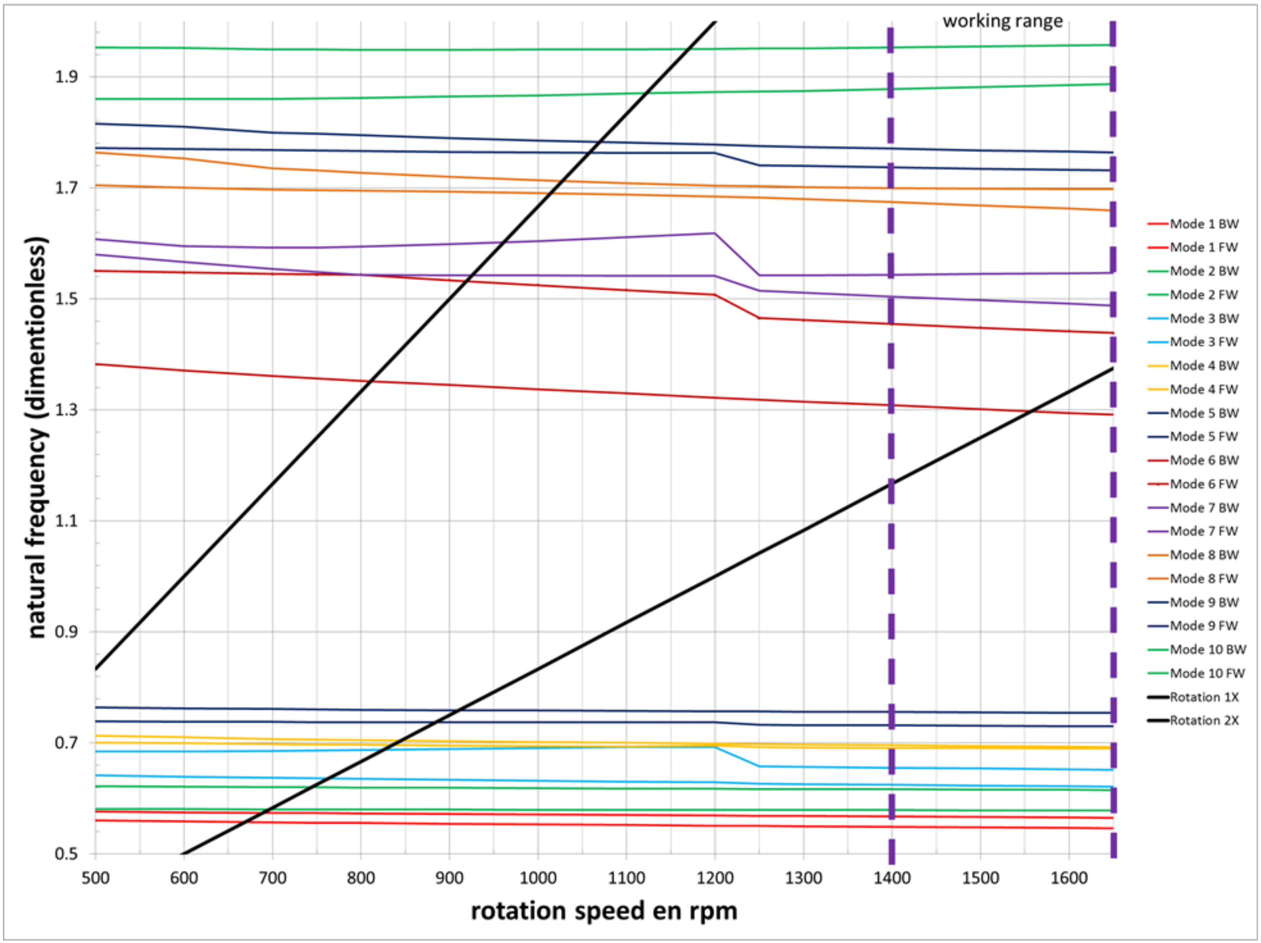

Figure 8 Campbell diagram of model with flexible pivot

This Campbell diagram shows that:

- A critical mode appears in the rotation speed range (intersection point of 1X black line and 11 mode red line). This mode could cause the resonance of the shaft line.
- The sudden change of natural frequencies for certain modes was observed. These results are due to the sudden change of the coefficients of bearing outcome of bearings calculation integrating flexible pivots.

Comparing with the results from the models without the flexibility of the pivot, there is also a decrease in natural frequencies after updating models.

Conclusion and technical/scientific prospects: (1/2 page including figures)

- Technical prospects

Following the results obtained about the dynamic analysis of the shaft line, an analysis of response to unbalance for the observed critical speed shall be considered to analyze the critical mode risk.

About the numerical model of the shaft line, the contribution of the support under bearings was minimized by using a simplified support. This simplified support is not entirely consistent with the real case. A better modeling might also be envisaged on this part.

The updated model is a numerical model and shall be tuned with respect to measurements done on site.

- Conclusion

The work and study during the internship allow building a more accurate numerical model. This updated model will be used in future studies on the GTA shaft line in 1300 at EDF.

Bibliography: (if needed, 1/2 page maximum)

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Several reports edited at EDF