

# **Benchmark para la evaluación y configuración de los cálculos dinámicos en una estructura industrial**

# Agenda

- Presentación
- Objetivos
- Antecedentes
- Desarrollo
- Trabajo futuro



# Presentación

- En el marco del proyecto de investigación SICOMORE, EDF realizó el proyecto SICODYN.
- Este proyecto consistió en la comparación de los resultados numéricos y experimentales de un análisis completo de vibraciones en una bomba bajo diferentes consideraciones.

# Objetivos

- Cuantificar la credibilidad de las predicciones numéricas en problemas de dinámica estructural
- Observar la variabilidad de las predicciones numéricas bajo condiciones de «incertidumbre»
- Caracterizar la incertidumbre o falta de conocimiento.
- Cuantificar la incertidumbre.
- Medir la fidelidad de las predicciones numéricas
- Medir la mejora de los modelos numéricos usando datos experimentales

# Tipo de prueba

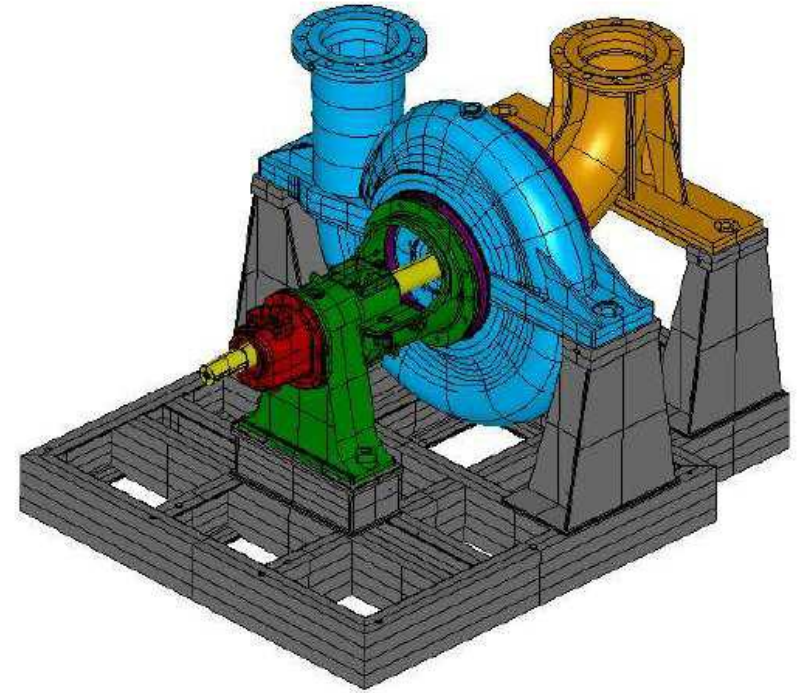
- Prueba académica? > **NO**
  - El proyecto no se refiere a mediciones experimentales sino a validaciones experimentales y estocásticas.
  - P.e. The validation challenge workshop
- Dispositivo de laboratorio? > **NO**
  - Simplificación de la estructura y el medio circundante
  - P.e. SMART CEA-EDF benchmark
- Estructura industrial con parámetros fijos? > **NO**

**ESTRUCTURA INDUSTRIAL EN CONDICIONES  
DE OPERACIÓN NORMALES**

# Estructura

- Características
  - Estructura industrial
  - Ensamble de diferentes componentes
  - Modelada en su ambiente
  - Fuentes de excitación desconocidas
- Restricciones
  - Disponibilidad de planos y modelos
  - Posibilidad de medir en condiciones de operación

# Estructura



# Objetivos EDF

- **HOY:** EDF solo exige a los fabricantes de bombas asegurar que las velocidades críticas de la bomba no estuvieran cerca de la velocidad nominal. Las simulaciones solo se enfocaban en el comportamiento dinámico del eje.
- **Nuevo requerimiento:** Para ciertas bombas los componentes estáticos deben estar lejos de las frecuencias de excitación.

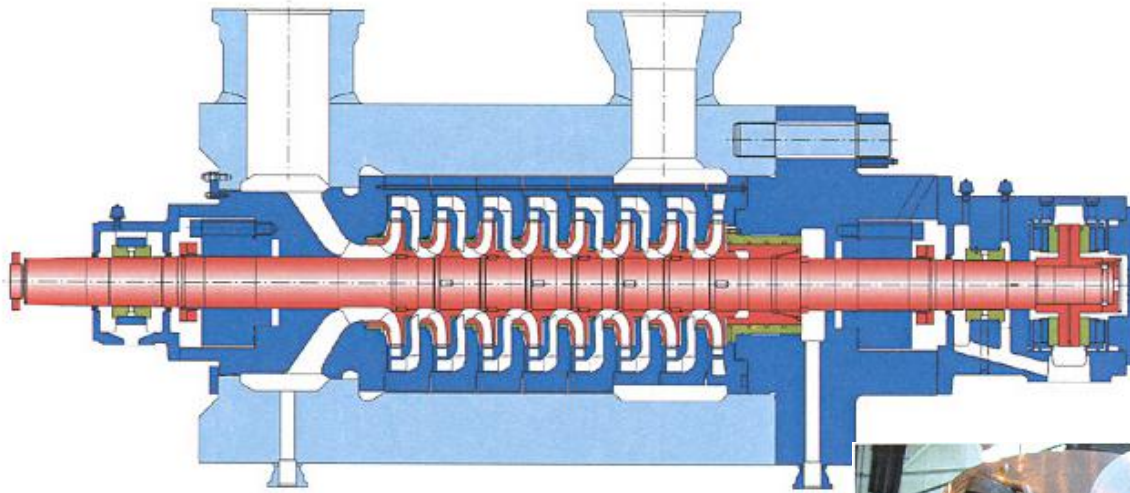
## 1. SICODYN benchmark definition

### List of partners (16)

- ◆ INSA Lyon
- ◆ FEMTO Besançon
- ◆ CETIM Senlis
- ◆ PHIMECA Engineering
- ◆ SAMTECH
- ◆ VIBRATEC
- ◆ EDF R&D
- ◆ (SULZER Pumps France)
- ◆ ILM Technology
- ◆ Ecole Polytechnique de Lausanne (Switzerland)
- ◆ Bristol University (United Kingdom)
- ◆ Politecnico di Milano (Italy)
- ◆ Gologanu (Roumania)
- ◆ MSO Industrial (Colombia)
- ◆ PIKITAN (Spain)
- ◆ CAEnable (USA)
- ◆ Delft University (The Netherlands)

# Antecedentes

- En 2001 Sulzer diseña la bomba de inyección más grande del mundo.
  - Especificaciones:
    - Potencia: 27 MW
    - Caudal: 250,000 barriles de agua de mar día
    - Presión: 480 bares
    - Peso: 19.8 Toneladas
    - Unidad motriz: turbina Rolls-Royce@4800 RPM



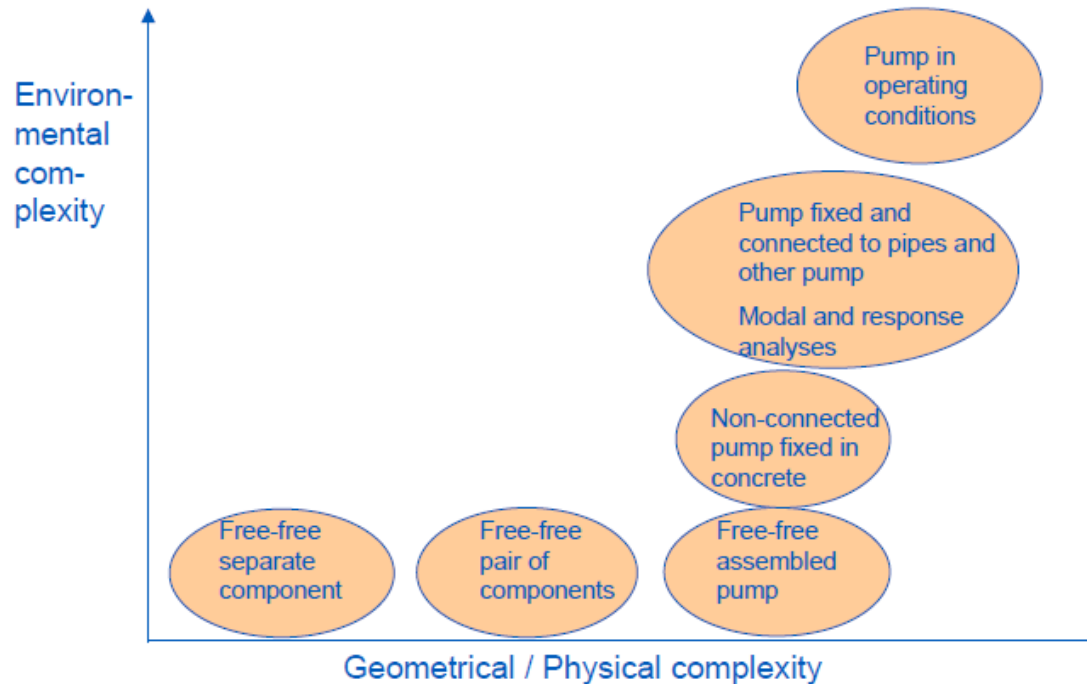
# Antecedentes de SICODYN

- Sulzer requiere garantizar que la bomba cumplirá con la vida especificada por el equipo.
- Adicionalmente que mantendrá las vibraciones de la bomba en niveles permisibles.
- Por esta razón decide implementar el proyecto de validación de pruebas numéricas y simuladas bajo condiciones controladas.
- EDF en el 2008 retoma el proyecto pero esta vez para condiciones normales de operación de la bomba.

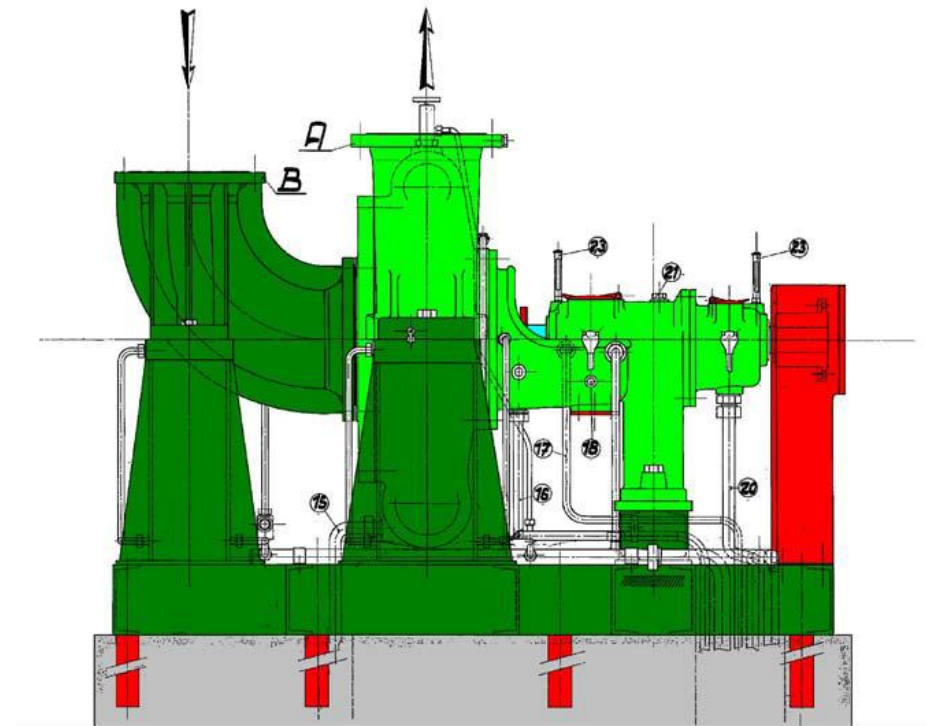
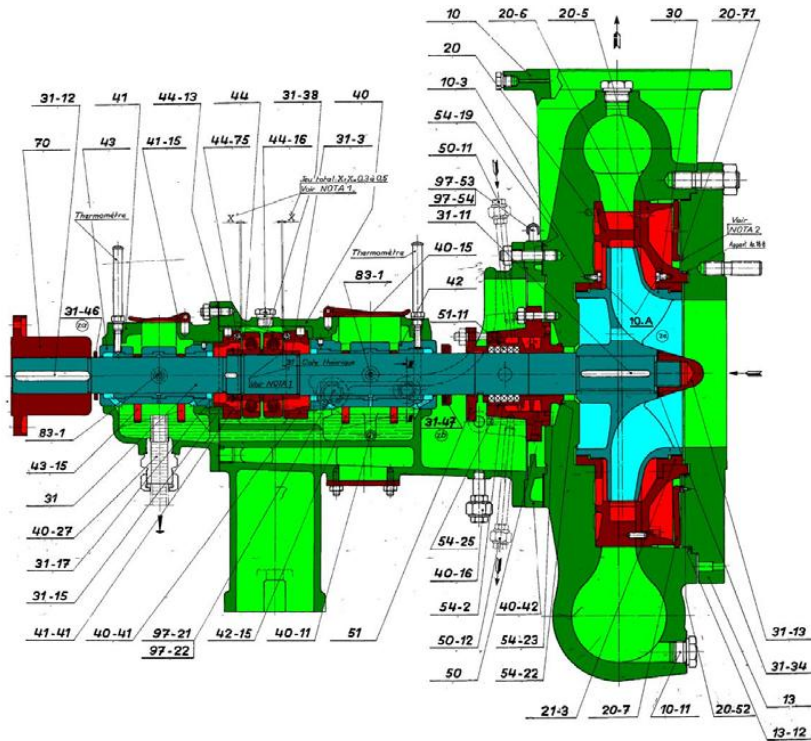
# Desarrollo

## 1. SICODYN benchmark definition

### Hierarchical process

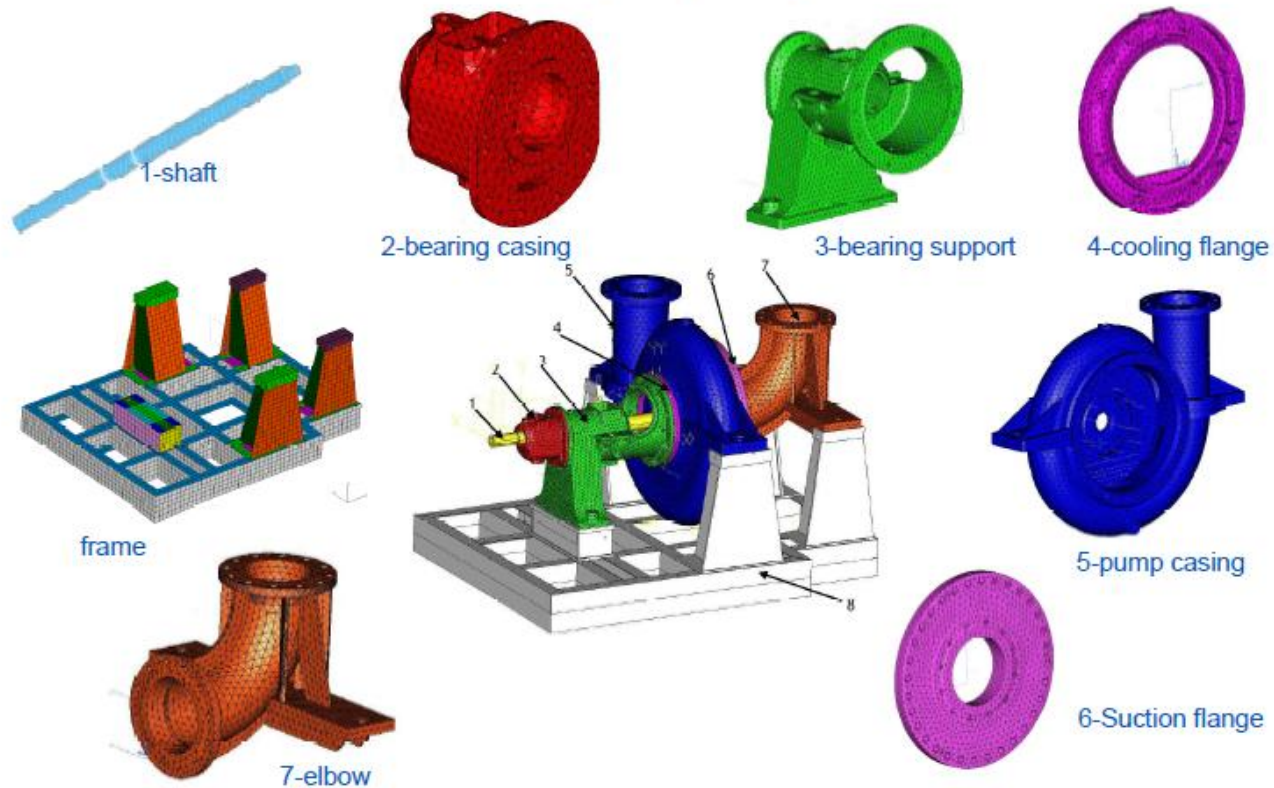


# Modelo de la bomba



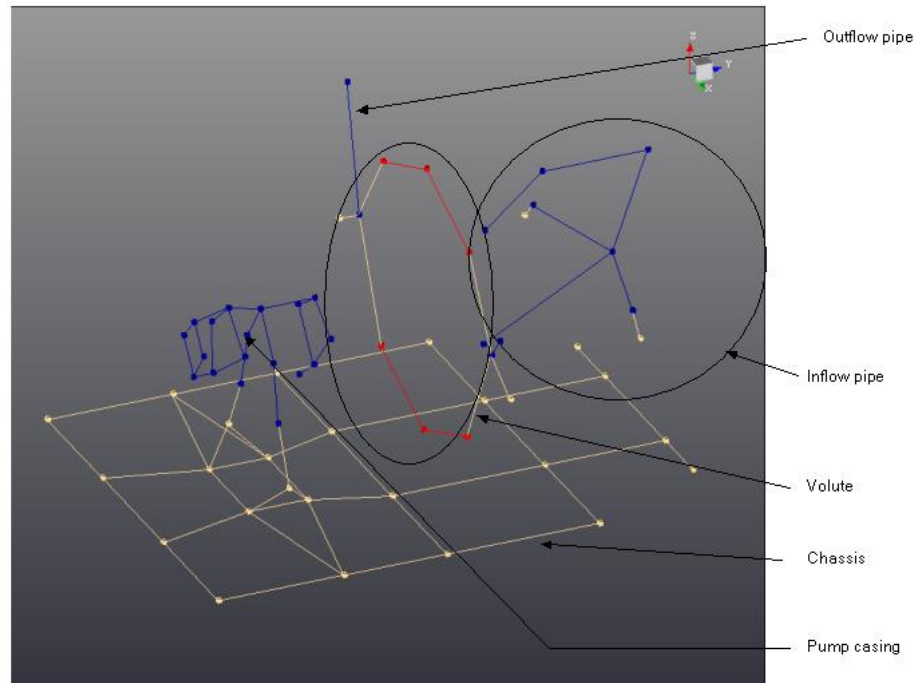
# Modelo de la bomba

## The 8 main pump components



# Herramientas

- LMS Polymax para la captura y análisis de datos



# Materials

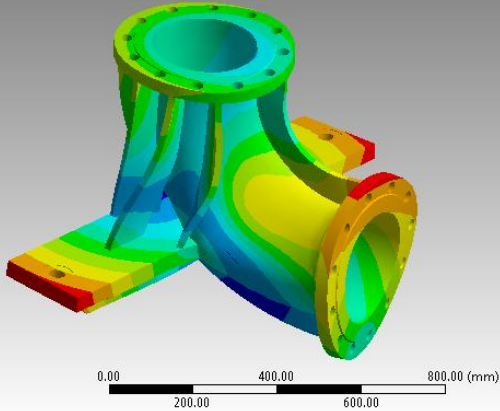
mean discrepancy (%)	Steel	cast iron
density ( $\text{kg/m}^3$ )	0.4	5.0
Young's modulus (Gpa)	1.8	18.7
Poisson's ratio	3.1	5.7

Table 2: mean discrepancy on material characteristics

# Resultados

**G: P65307\_Elbow**  
 Total Deformation  
 Type: Total Deformation  
 Frequency: 343.2 Hz  
 Unit: mm  
 07/04/2011 03:17 a.m.

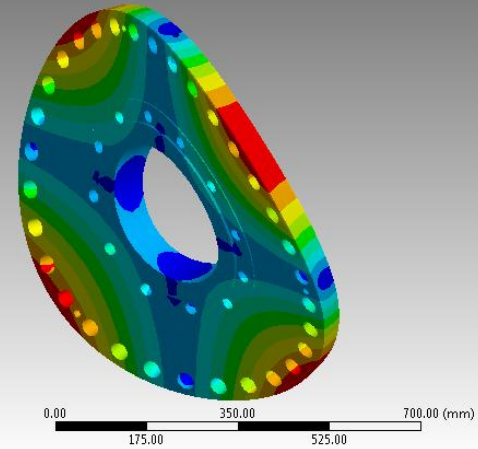
**4.3333 Max**  
 3.8567  
 3.38  
 2.9033  
 2.4266  
 1.9499  
 1.4733  
 0.99659  
 0.51992  
**0.04324 Min**



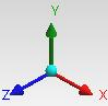
**ANSYS**  
13.0

**C: P64218\_Suction\_flange**  
 Total Deformation  
 Type: Total Deformation  
 Frequency: 552.61 Hz  
 Unit: mm  
 07/04/2011 03:16 a.m.

**5.0486 Max**  
 4.4906  
 3.9325  
 3.3744  
 2.8164  
 2.2583  
 1.7002  
 1.1422  
 0.5841  
**0.026039 Min**

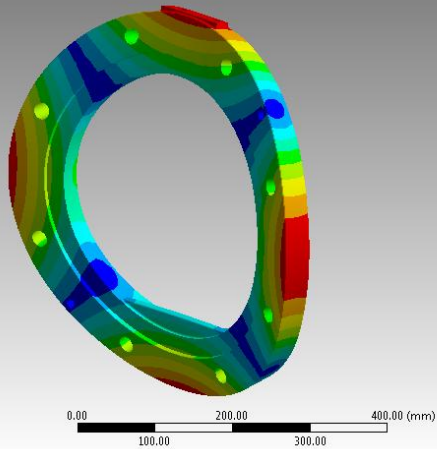


**ANSYS**  
13.0



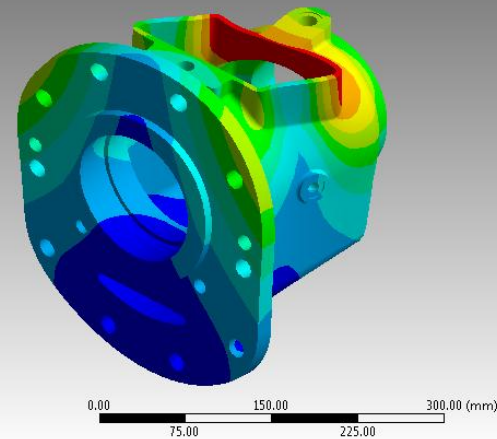
**A: P62752\_Cooling\_flange**  
 Total Deformation  
 Type: Total Deformation  
 Frequency: 360.3 Hz  
 Unit: mm  
 07/04/2011 03:11 a.m.

**14.058 Max**  
 12.5  
 10.941  
 9.3821  
 7.8233  
 6.2645  
 4.7057  
 3.1469  
 1.5882  
**0.029375 Min**

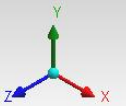


**B: P64216\_Bearing\_casing**  
 Total Deformation  
 Type: Total Deformation  
 Frequency: 1309. Hz  
 Unit: mm  
 07/04/2011 03:13 a.m.

**20.01 Max**  
 17.787  
 15.564  
 13.341  
 11.118  
 8.8944  
 6.6711  
 4.4479  
 2.2247  
**0.0015048 Min**



**ANSYS**  
13.0



# Resultados porcentuales

- Comparación entre equipos

Pump component	Mean discrepancy / mean value (%)
Elbow	< 5
Frame	< 20 (< 7 if one team excluded)
cooling flange	<13
bearing support	< 10
bearing casing	< 10
suction flange	< 3
pump casing	< 15

Table 3: mean numerical eigenfrequency discrepancy / mean numerical eigenfrequency value

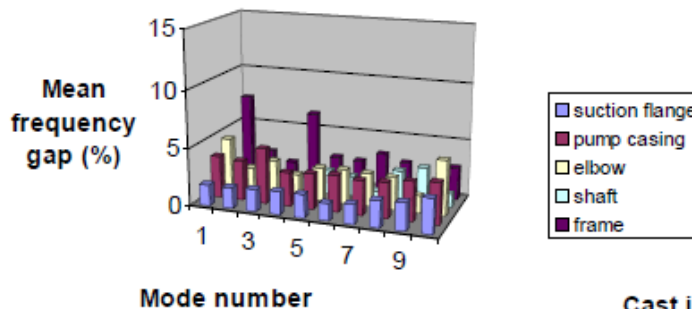
- Comparación con resultados experimentales

Pump component	Mean discrepancy / experimental value (%)
shaft (after updating)	<7
bearing support	<23
pump casing	<21

2. Total variability of numerical predictions in blind conditions

## Variability of separate pump component eigenfrequencies

Steel pump components



Steel pump components

2% variability on Young's modulus

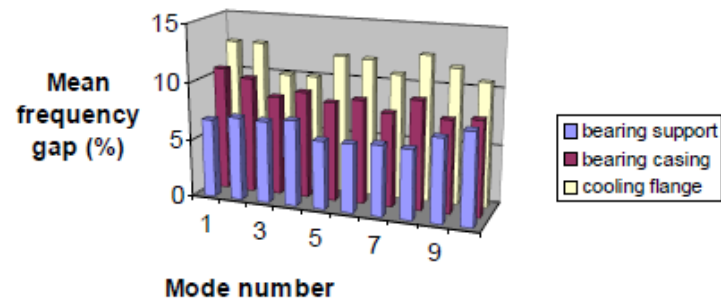
5% mean variability on eigenfrequency values

Cast iron pump components

20% variability on Young's modulus

11% mean variability on eigenfrequency values

Cast iron pump components

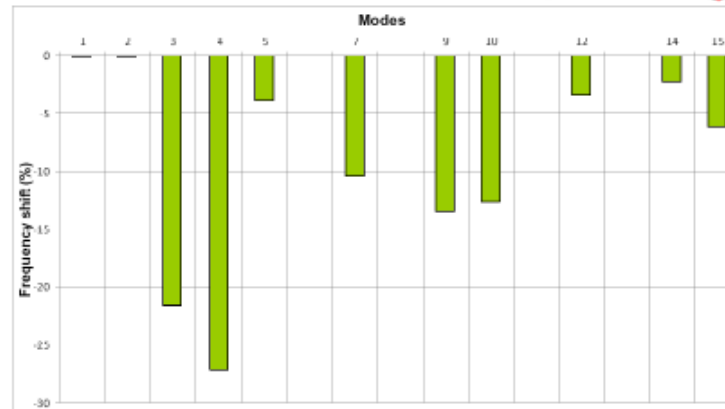
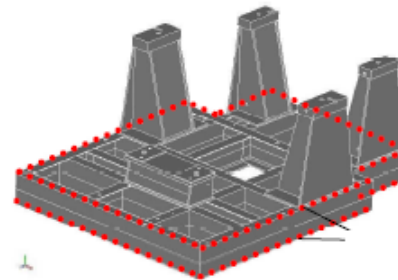


3. Parametrical study on boundary conditions

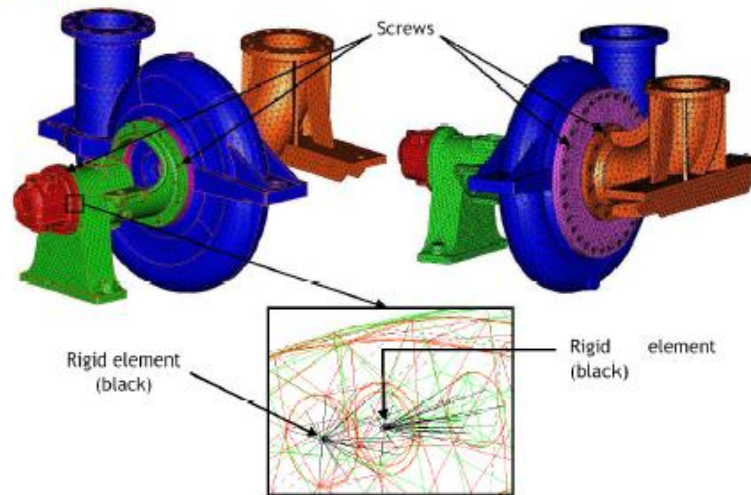
## Parametrical analysis on the clamped boundary condition

Configuration 1: frame completely fixed in concrete

Configuration 2: frame partially fixed in concrete



## Representation of connections between pump components



Bolted assembly: rigid connections via rigid relationships, elements or stucked surfaces

Ball and hydrodynamic bearings: estimated radial and axial stiffnesses

#### 4. Measurement uncertainty

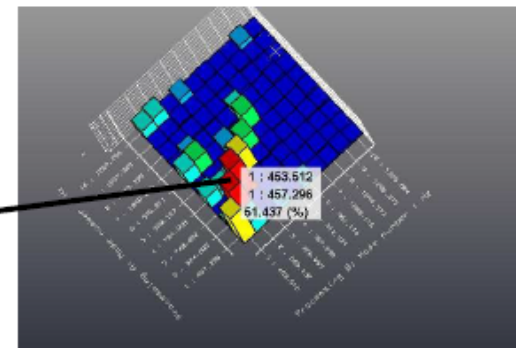
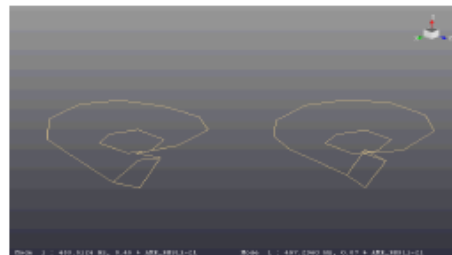
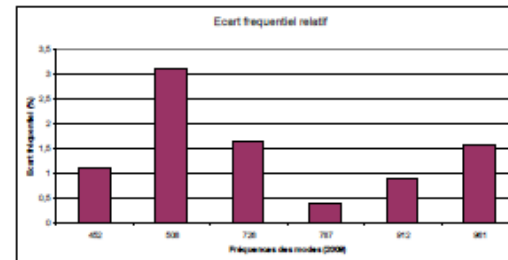
## Focus on: variability between two measurements

### ▶ Example : pump casing

- One modal analysis in 2009, the other one in 2010 at Sulzer Service in Velaux (Marseille)
- Same methods and means of measurements
- Two operators and two different structures

### ▶ Outstanding conclusions

- Ability to pair modes from each experiment
- Frequency shift: max 3%
- BUT: maximum MAC between pairs is lower than 60%

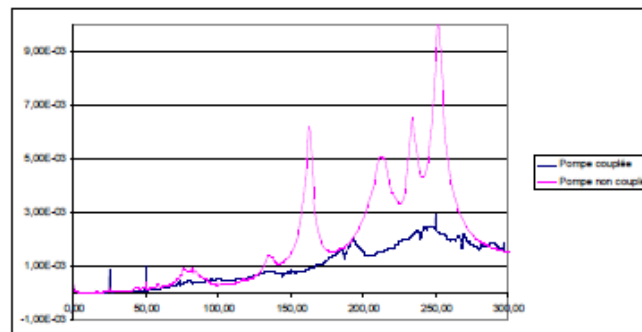


#### 4. Measurement uncertainty

## Focus on: pump connected to pipes

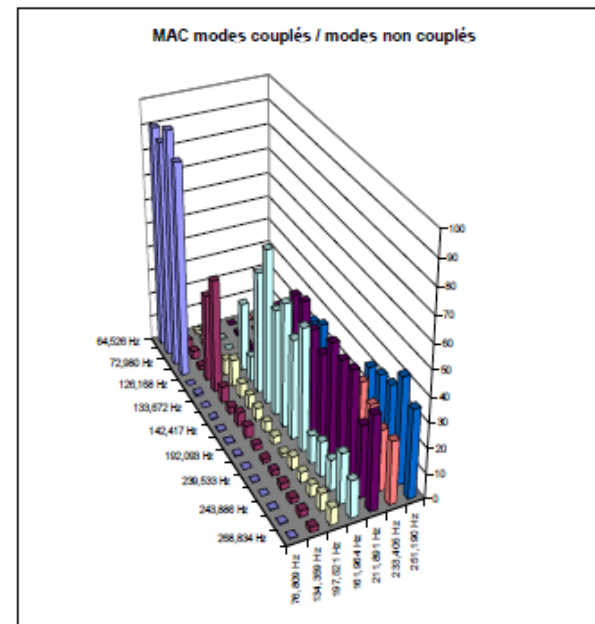
- ▶ Modal analysis is more difficult to do

- Modal sum:



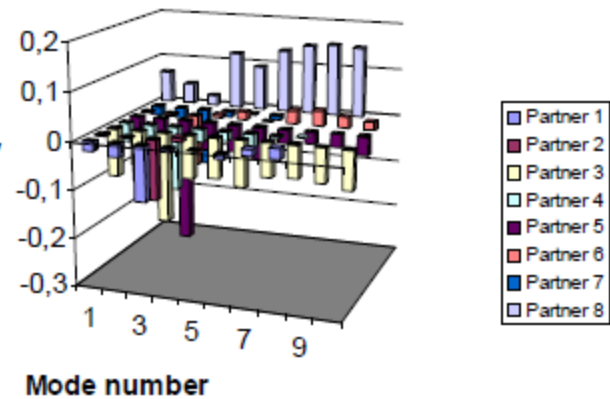
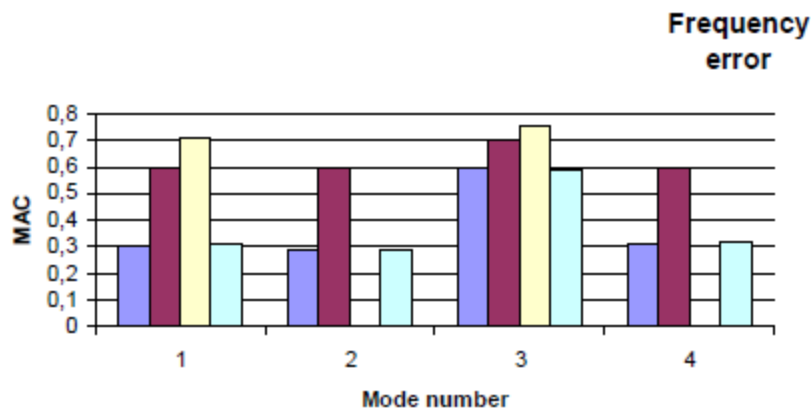
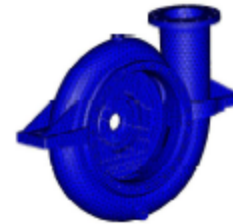
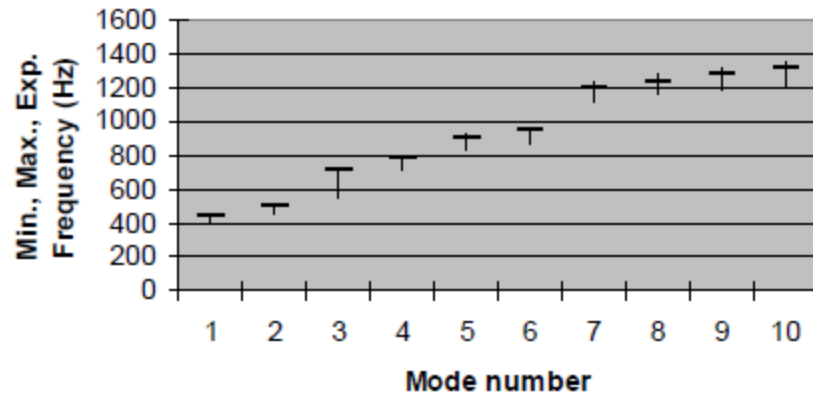
- ▶ Correlation is OK for first mode

- But more difficult on other shapes



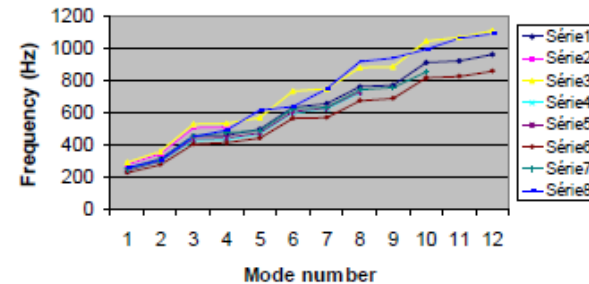
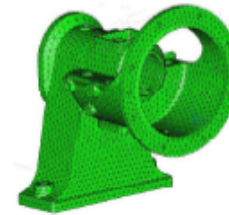
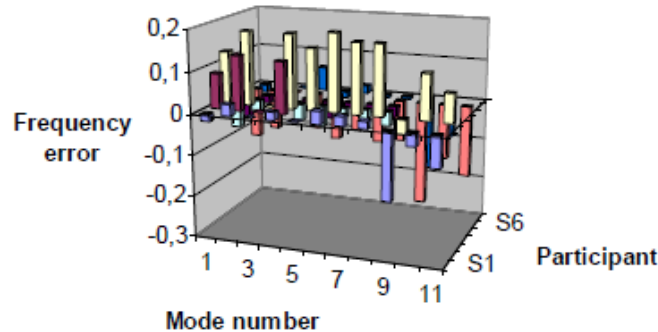
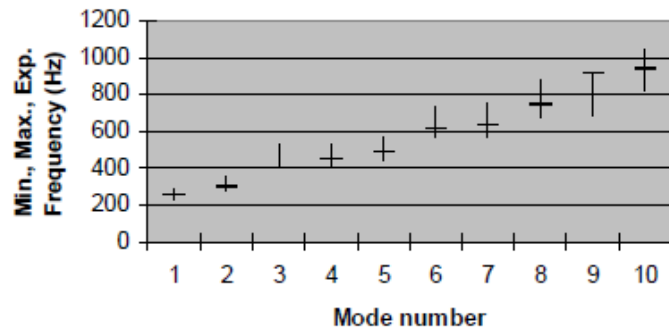
5. Numerical-experimental correlation

Experimental-numerical comparison of separate component modal analyses:  
the pump casing example



5. Numerical-experimental correlation

# Bearing support

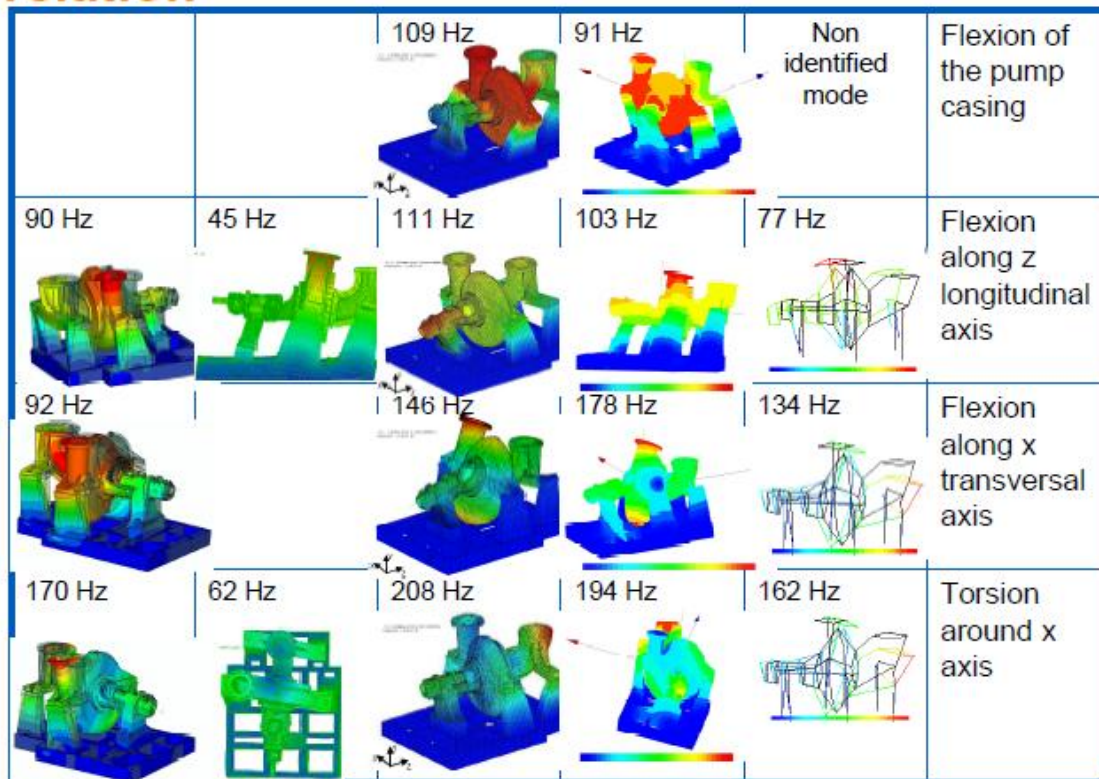


3rd experimental mode missing

Experimental values between min-max numerical values

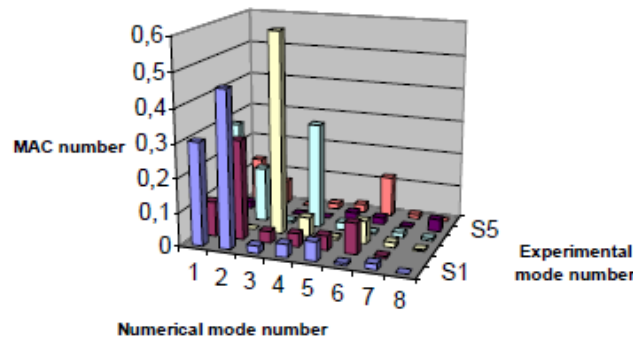
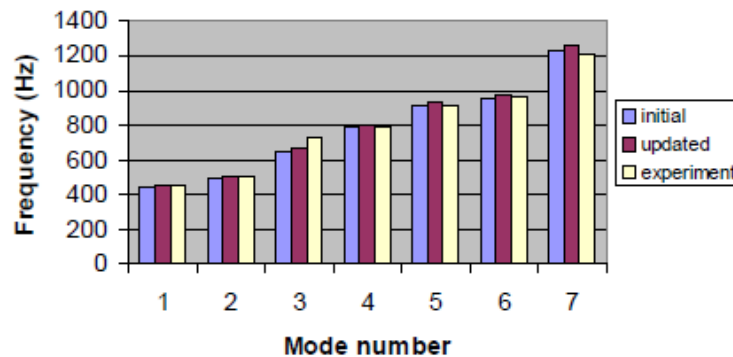
5. Numerical-experimental correlation

## Pump assembly: numerical-experimental correlation



5. Numerical-experimental correlation

**Example of updating results for the pump casing component**



Mode	initial	updated
1	-2.0	0.4
2	-2.8	-0.3
3	-11.3	-9.1
4	-0.6	1.9
5	0.0	2.5
6	-1.1	1.4
7	1.5	4.0

Frequency error (%)

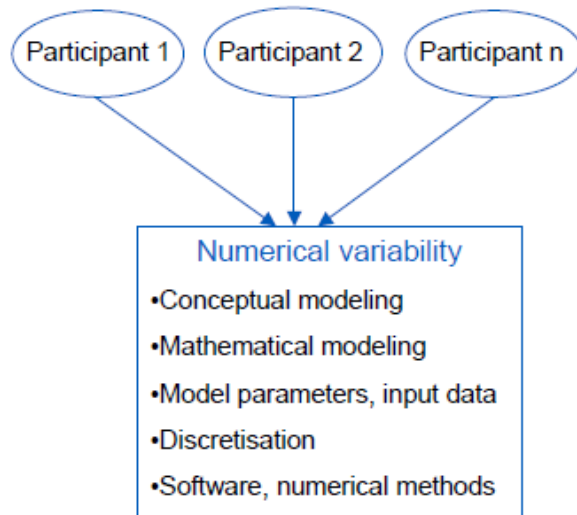
Young's modulus:  $2.0E+11 \rightarrow 2.1E+11$

Density:  $7800 \text{ kg/m}^3$  unchanged

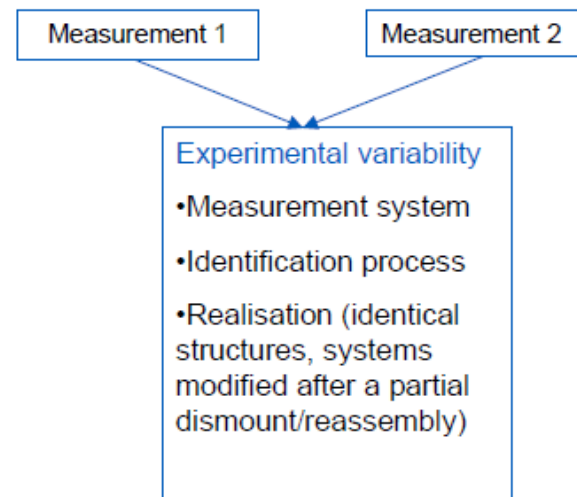
Poisson's coefficient: 0.3 unchanged

## Purpose for a comparative and updating process

### ◆ Compare numerical results



### ◆ Compare experimental results



### Compare numerical-experimental results

Fidelity to test data

## 6. Conclusion

# Conclusion on reliability on modal models of sub-structures

### ▶ Numerical aspects

- Narrow numerical variability on eigenmodes

### ▶ Numerical-experimental correlation

#### Blind simulations

- Experimental eigenfrequency values are within the min.-max. numerical eigenfrequency value interval
- Modeshape correlation not quite satisfactory (based on MAC criterion)

#### Updated simulations

- Improvement of the eigenfrequency values, but MAC unchanged

### ▶ Ability of numerical models to accurately predict the global modal behaviour of a complex structure

### ▶ Is the updating of the sub-structure model parameters necessary to increase the reliability of the built-up structure ?

## 6. Conclusion

### Questions to be pointed out

- ◆ Can a purely blind numerical model accurately represent the dynamical behaviour of a built-up structure in its environment ?
  - What are the relative parts of the modeling error and the parametrical error ?
  - Can a parameter updating compensate the modeling error ?
  - What parameter variations are acceptable, in order to obtain an admissible numerical model (i.e. which intercepts the experimental set of output data) ?
- ◆ What are the minimal adequate experimental measurements necessary to obtain a confident model ?
  - What necessary measurements, function of the final use of the numerical model ?
- ◆ What modelisation points to first improve (connection representations, boundary conditions, sub-structure models)?



## **SOLUCIONES AVANZADAS DE INGENIERÍA**

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