FINAL EXAM – MN44

- **Exam duration: 2 hours.**
- **Each answer must be both correct and well-presented (clear and concise).**
- **Each party will be written on a different copy.**

PART 1 (UTBM: CHAMORET, LEBAAL AND ROTH)

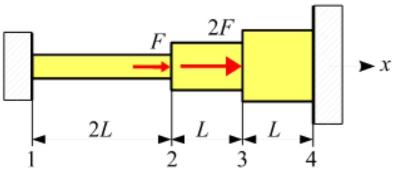
- **Documents not allowed**
- **New copy!**

A. ANSWER TO THE QUESTION. JUSTIFY YOUR ANSWER IN 5 LINES MAXIMUM.

1. What is a static linear study? Explain.
2. List and explain three types of nonlinearities in FEM analysis.
3. Constitutive laws.
    a. Is the Hooke law sufficient, if you want to study the rupture of a material? Explain your answer.
    b. Name another well-known constitutive law usually used for steel material.
4. List and explain classical errors inherent in FEM Formulation.

B. EXERCISE

We study a beam under nodal loadings, composed of an assembly of three parts with three different sections, as illustrated on the following figure.



The system is discretized into 3 elements linked by nodes 1, 2, 3, 4. The beam is clamped on the two extremities (node 1 and 4). The section of each parts are A, 2A, and 3A respectively. The length of each parts are 2L, L and L respectively. Two loads F and 2F are applied respectively on nodes 2 and 3.

MECHANICAL ANALYSIS

The elementary matrix of a beam with a section S, with a length l, is:

$$\frac{E.S}{l}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}.$$

1. Write this equation for each element (for each node i and j).
2. Assembly the final matrix in order to obtain the global equation: K.U=F.
3. Use the boundary conditions to solve the global equation, and find $u_i, \forall i$.
4. Use the Hooke's law (1D, $\sigma = E.\frac{\partial u}{\partial x}$), calculate the stress for each elements.

THERMAL ANALYSIS

If the truss is mechanically *unloaded*, and its proper weight is negligible that is, F=0 and $\rho g A L$ =0. However the temperature of members changes by $\Delta T = 20°C$, with respect to *Tref* . The thermal expansion coefficient of all three members is assumed to be *α=12. 10⁻⁶*. The elementary matrix of a beam with a section S, with a length l, is:

$$\frac{ES}{l}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{Bmatrix} \rho g S l/2 \\ \rho g S l/2 \end{Bmatrix} + \begin{Bmatrix} f_1 \\ f_2 \end{Bmatrix} + ES\alpha\Delta T\begin{Bmatrix} -1 \\ 1 \end{Bmatrix}$$

5. Use the boundary conditions to solve the global equation, and find $u_i, \forall i$.
6. Calculate the stress for each elements. Such as the total strain is the sum of the mechanical and the thermal strains: $\varepsilon = \varepsilon_M + \varepsilon_T = \frac{\sigma}{E} + \alpha\Delta T$.

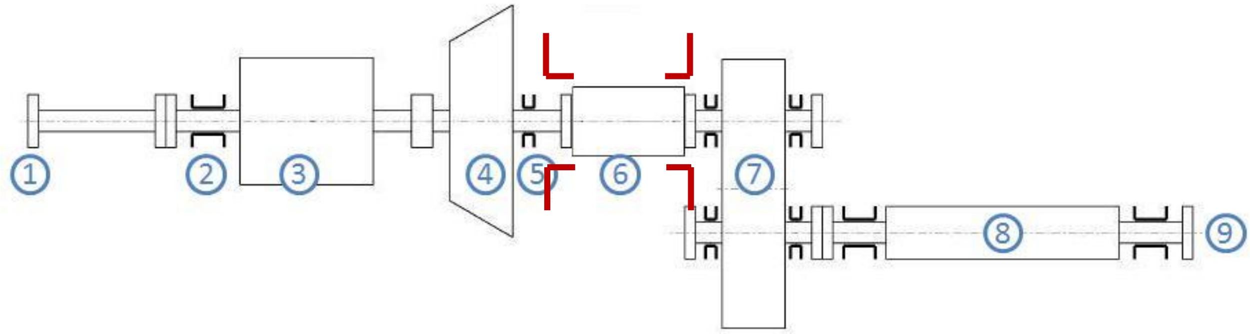
PART 2 (GE 1 : H. GONON)

- **Course material is allowed**
- **New copy!**

The diagram below represents the installation of 6B gas turbine.

Coupling is a part of rotor. Its function is to transmit torque between two systems of the power train (turbine and load gear, or turbine and generator).
Coupling are often designed to be flexible (due to alignment of the power train requirements) at each end. Flexible parts are critical and guards are added to contain coupling (rotation speed @ 3000 rpm) in case of failure.

Diagram of the system:
1: start up system
2: bearing
3: compressor
4: turbine
5: bearing
6: coupling
Guards coupling
7: Gear box
8: Generator



A catastrophic event occurred on-site. During operation, flexible coupling flanges (gas turbine side and gear box side) broke suddenly. Coupling guards, designed to contain flexible coupling in a limited volume in this kind of situation, failed too. Coupling fell down and damaged an oil pipe, causing a fire.

We would like you to:

- Explain why the guards coupling didn't perform correctly its duties and broke.
- Propose a new design.

What strategy and what means could you implement to reach this request?

Remarks:

- You cannot go on site but you can retrieve the broken parts and you can have pictures.
- You access the operating parameters of the installation at the time of rupture (speed, temperatures, vibration response)

PART 3 (GE 2: O. CHAPUIS)

- **Course material is not allowed**
- **New copy!**

Part A provides all the useful information to perform the exercises of part B.

A. AVAILABLE INFORMATION

Main step to build a bondgraph

1/Make a schematic diagram of the system.

2/ Lumped approach :
Split sytem into sub system having same P,T.
Use Arrows and symbols to indicate the positive direction of mass & NRJ flow

3/ For each distinct Pressure or temperature etablish a « 0 » junction

4/Insert R or IR elements between appropriate 0-junctions to represent mass or NRJ flow. Half arrow must have the same direction as Mass & NRJ flow

5/Attach Se or C-element to 0-junction to represent system dynam capacitance or boundary condition

6/ Simplify the Bond graph : ⟶0⟶ = ⟶1⟶ = ⟶

7/Affect the causality

8/Numbering all the bond in consecutive order

9/Derives equations starting with the state variable having the lowest bond number.

10/Derives equations starting with the flow variable having the lowest bond number.

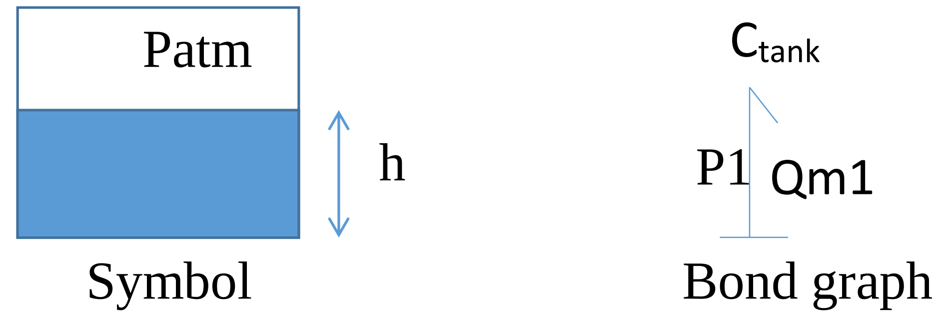
11/Sort equation : such that the updated information required to evaluate an expression has already been computed

Hydraulic component library

The capacitive component : Hydraulic Tank

On the picture below, are recalled:

- On the left : the icon that represents a hydraulic tanks
- On the right the corresponding bondgrah component.



The set of equations for such a system are:

- The mass balance :

$$\frac{dm}{dt} = Qm_1$$

- Algebraic relations that link the state m and the potential P :

$$P = Patm + \rho g h$$
$$m = \rho * S * h$$

- The initial conditions computations that link the initial height in the tanks with the initial liquid mass and pressure :

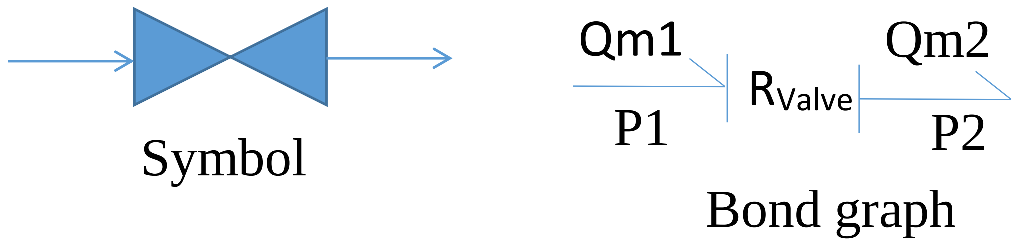
$$P_0 = Patm + \rho g h_0$$

$$m_0 = \rho * S * h_0$$

The resistive component: Laminare Valve

On the picture below, are recalled:

- On the left : the icon that represents a laminare valve
- On the right the corresponding bondgrah component.



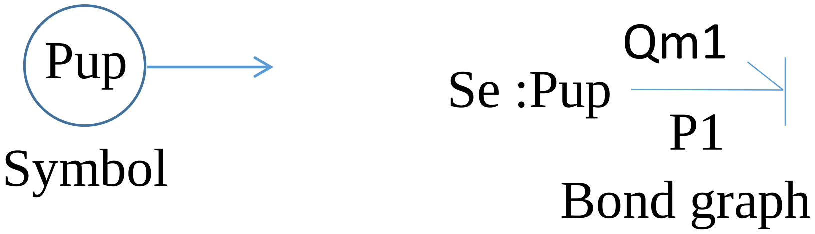
The set of equations for such a system are:

$$Qm1 = Qm2 = \frac{1}{R_{valve}}(P1 - P2)$$

The source of pressure

On the picture below, are recalled:

- On the left : the icon that represents a source of pressure
- On the right the corresponding bondgrah component.



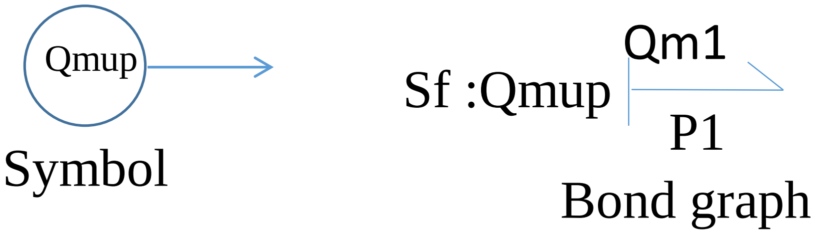
The set of equations for such a system are:

$$P1 = Pup$$

The source of Mass flow rate

On the picture below, are recalled:

- On the left : the icon that represents a source of mass flow rate
- On the right the corresponding bondgrah component.

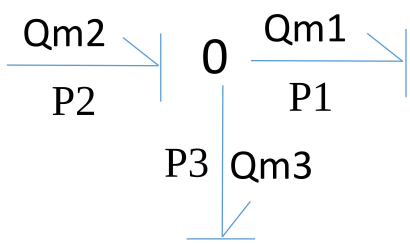


The set of equations for such a system are:

$$Qm1 = Qmup$$

The node component

On the picture below, are recalled the node component of the bondgraph



The set of equations for such a componet are:

- The kirschoff law :

$$0 = Qm2 - Qm1 - Qm3$$

- The equality of pressure

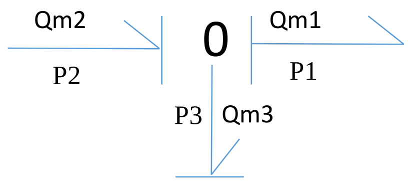
$$P1 = P2 = P3$$

B. EXERCICE

Exercice 1

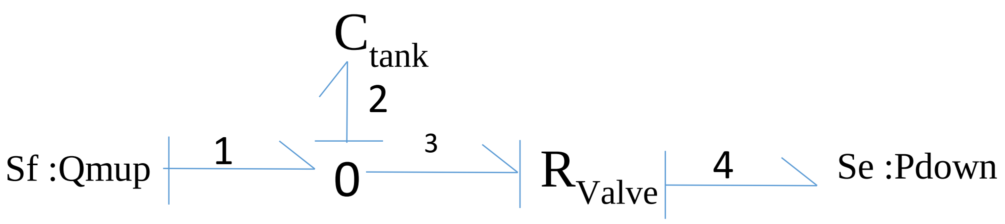
1) According to the picture below please explain which system imposes the effort, which one impose the flow, what is the direction of the positive flow

2) Is the bond graph below is correct? why?



Exercice 2

3) Using the library of component provided in part A , write the set of equations corresponding to the bond graph below. Then sort the equations in order to be solved. (Recall: a variable could be used only if it has been computed before)



4) Using the library of component provided in part A , write the bondgraph corresponding to the schematic below :