<u>Experiment No: 3</u>

Pump flow control and Motor efficiency

Part A. Efficiency testing of pump

Objective:
To compare different methods of flow control for centrifugal pumps

Set-up:
A centrifugal pump drives water in a closed loop back to a water supply tank. The three phase induction motor driving the pump is rated at 7.5 HP and is equipped with a Variable Speed Drive. Pressure gauges are present for measurement of suction and discharge pressures from the pump. An orifice plate is inserted in the discharge with the pressure difference measured using a manometer

Schematic Diagram:

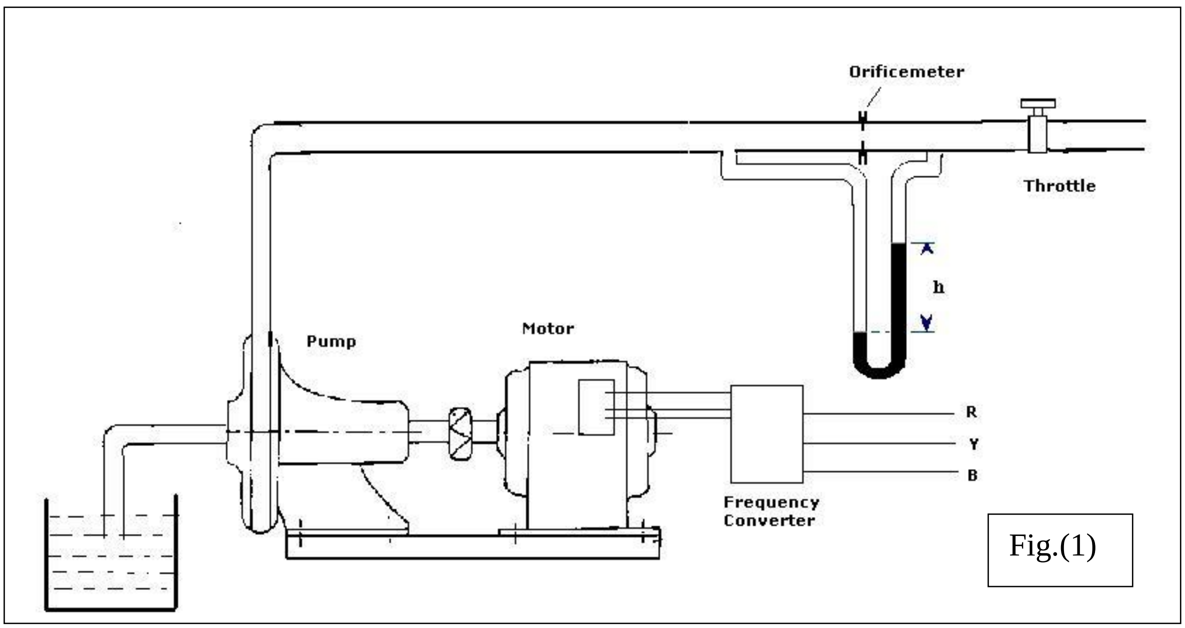

Fig.(1)

Theory:

Pump System Characteristics

Water pumping accounts for a significant part of India's electricity consumption. In order to pump liquid through the system at a certain flow rate, it is necessary to increase the pressure of the liquid. This pressure has to be high enough to overcome the resistance of the system, which is also called "head". The total head is the sum of the static head and the friction head. Most pumping systems have characteristics as shown in fig (2a). The performance of a pump can be expressed in terms of the variation in the head versus the flow. A centrifugal pump has a curve as shown in fig (2b)

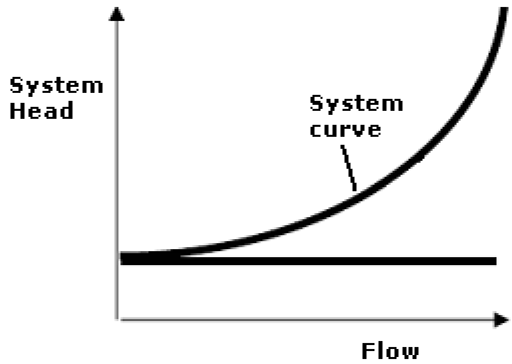

Fig.(2a)

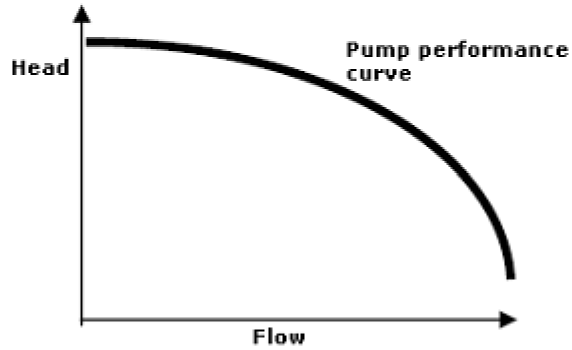

Fig.(2b)

For a given network with a fixed static head, the system head required increases with the flow rate as shown in fig. (2a).When a pump is installed in a system the effect can be illustrated graphically by superimposing the pump and the system curve. The operating point is the intersection of these two curves. [Refer fig.(3)]

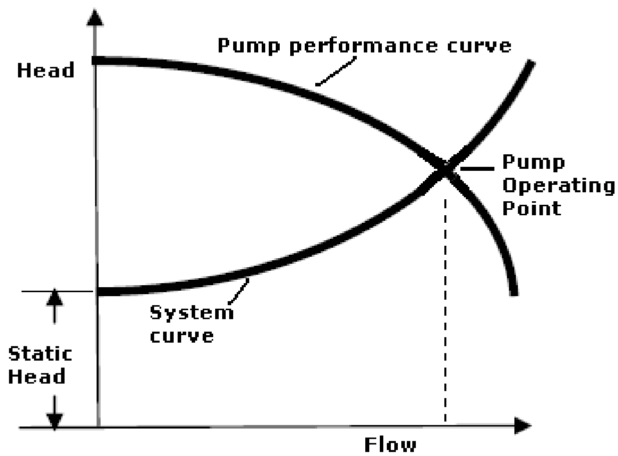

Fig. (3)

In many pumping applications, the flow requirement is less than the design value. This is due to over sizing, planning for future expansion etc. In order to control the pump flow rate, the options available are bypass control, throttling, varying the speed.

Flow control methods

1. **Bypass control** – In this method the pump operates at the design point. The surplus flow is bypassed back to the supply tank. The input power required remains constant (at the rated power). This method is only used for fine control near the design operating point.

2. **Throttling** - In this method the system resistance is increased by partially closing one or more valves at the outlet end. The system characteristic changes and the operating point shifts. There

is a throttling loss across the throttle valve. The head developed is higher than the minimum head required for that flow. [Refer fig. (4)]

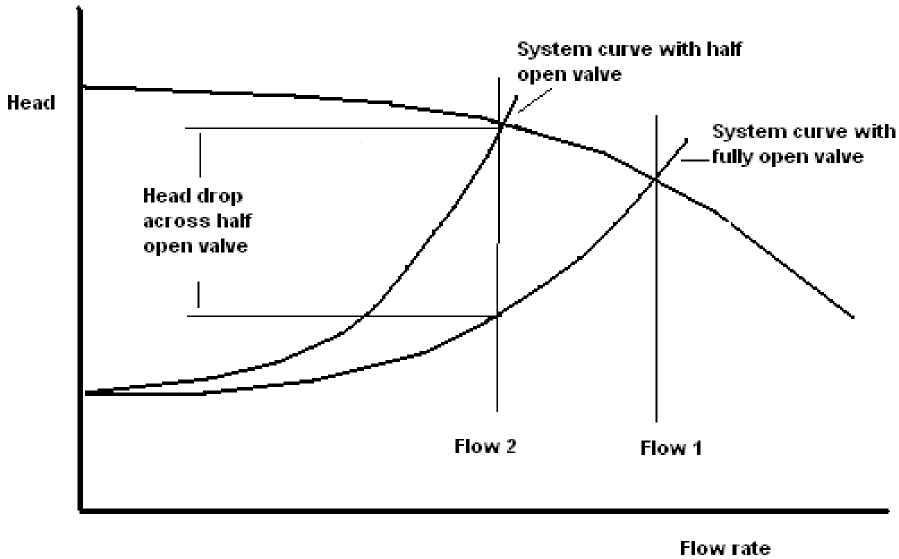

Fig. (4)

3. **By speed variation**

In this method the pump characteristic is changed by changing the operating speed of the motor. The pump performance parameters (flow rate, head and power) change with varying rotational speeds. The equations that explain these relationships are known as affinity laws

- Flow Rate (Q) is proportional to Rotational speed (N)
- Head (H) is proportional to the square of the rotational speed
- Power absorbed (P) is proportional to the cube of the rotational speed.

As can be seen from the above laws a small reduction in speed can cause large reduction in power consumption. Throttling also reduces the flow rate but not the energy consumed by the pumps. Variable frequency drives enables the smooth control of rotational speed by controlling the supply frequency

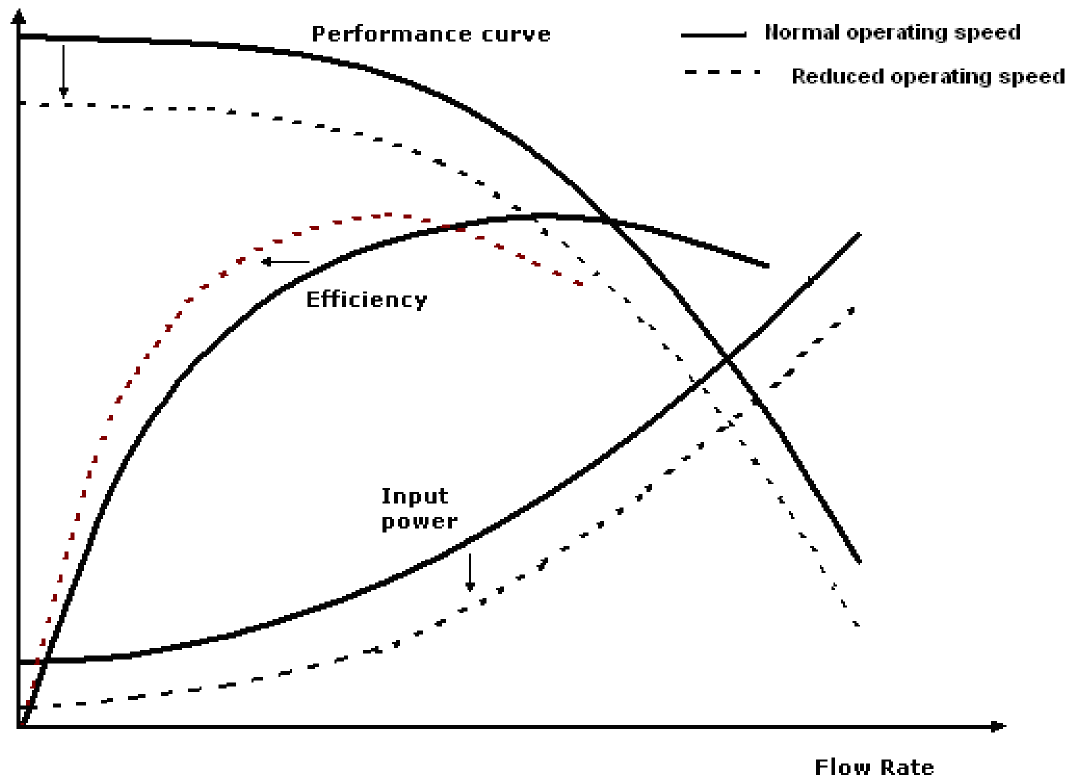

Fig.(5) Effect of Variable Speed Drive

Procedure:

It is required to run the pump for different flow rates by (a) Throttling and by (b) Variable Speed Drive.

In (a) ensure that the bypass is closed(Q=0). Obtain different flow rates by changing the resistance of the throttle valve. In each case note the input power consumption, the suction and discharge pressures and the pressure drop across the orifice. Calculate the useful work output of the pump and the efficiency. (Take at least four different readings)

For (b) obtain each of the previous flow rates(ie, approximately same manometer readings) by changing the speed of motor using variable speed drive. Compute the efficiencies for the operation.

Plot the input power and efficiency aganist flow rate for both control strategies.

Precautions:

- Increase the flow rate gradually, so that mercury will not flow out of the manometer tube.
- Ensure there is no air columns in the tubes connected for pressure measurement.
- Use only the middle discharge pipe while conducting the experiment and ensure that the proper valves only are open.

Formulae:

Flow rate is calculated as

$$Q = C_d \frac{1}{\sqrt{\left(\frac{D_1}{D_2}\right)^4 - 1}} \frac{\pi}{4} D_1^2 \sqrt{2\frac{(p_1 - p_2)}{\rho}}$$

where p_1-p_2 =$h(\rho_m$-$\rho_w)g$
D_1 = 1.5 inch; D_2 = 1 inch, C_d = 0.7

Pump output power is given by $P = \rho g Q H$

Where H is the total dynamic head (Difference between discharge and suction pressures expressed in metres of water)

Observation Tables:

Throttling:

No	Power Input Pin (kW)	Manometer Reading (cm of Hg)			Suction Pressure Ps	Discharge Pressure Pd	Supply Frequency f (Hz)	RPM	Flow Rate Q (m3/s)	Total Head H (m)	Power Output Po (kW)	Efficiency η (%)
		h1	h2	(h1-h2)								
1												
….							50					
7												

Variable speed drive:

No	Power Input Pin (kW)	Manometer Reading (cm of Hg)			Suction Pressure Ps	Discharge Pressure Pd	Supply Frequency f (Hz)	RPM	Flow Rate Q (m3/s)	Total Head H (m)	Power Output Po (kW)	Efficiency η (%)
		h1	h2	(h1-h2)								
1												
….												
7												

Error Analysis:

For doing error analysis note down the least counts of the instruments used for measurements and also the fluctuations in the readings.

Results:

Conclusions:

Part B : Efficiency Testing of Motor

Objective:

To test the efficiency of a 3-phase induction motor (under field conditions) and to study the variation in efficiency with loading

Instruments used:

1. Portable 3-phase load manager
2. Digital Multi-meter
3. Non contact type tachometer
4. Panel meters on the load bank

Schematic Diagram:

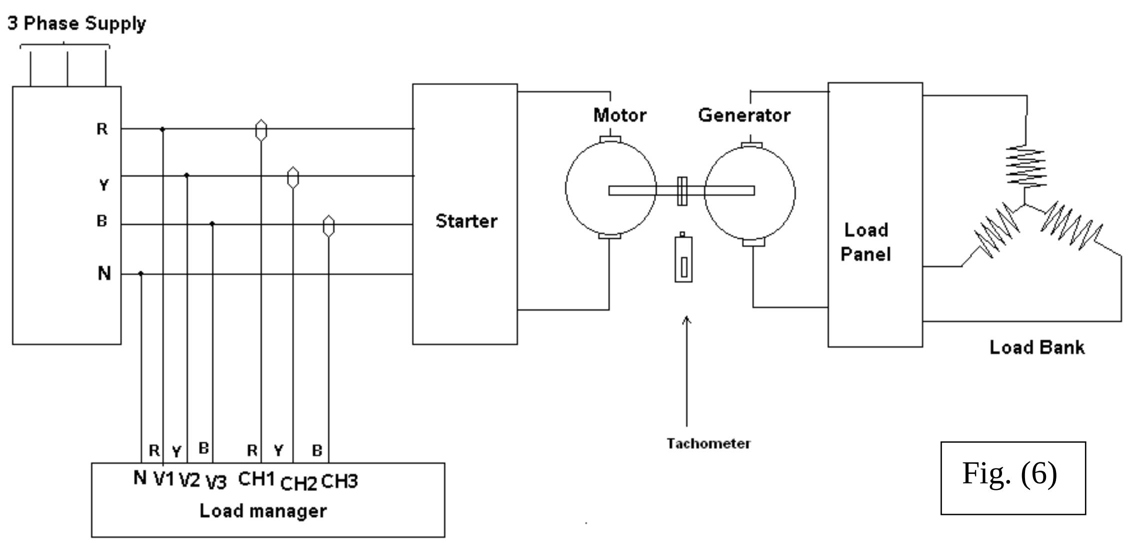

Fig. (6)

Specification of Motor Generator set:

(Alternator-Elmot Engg. Co. Pvt. Ltd.)	**(Motor-Crompton Greaves)**

Voltage: 415/240	Voltage: 415 V
kVA: 20/16	kW: 7.5
Amps: 27.9 A	Rating: Continuous
Power factor: 0.8	Power factor: 0.8
Phase: 3	Phase: 3
RPM: 1500	RPM: 1440
Frequency: 50 Hz	Frequency: 50 + 3%Hz
	H.P.: 10
	Temperature: 40^{0}C , Class B Insulation

Theory:

Motors account for about 60% of the total electricity consumption. The most commonly used motors are three phase induction motors. During an energy audit, it is required to determine the loading and operating efficiency of the major heavy duty motors. The method used is based on field testing of motors (IEEE Std 112-1984, JEC 37, IEC –34-2, ISI –4889).
The various losses in an induction motor are shown using the following figure [Fig(7)].The typical efficiency curve of the induction motor is shown in fig.(8)

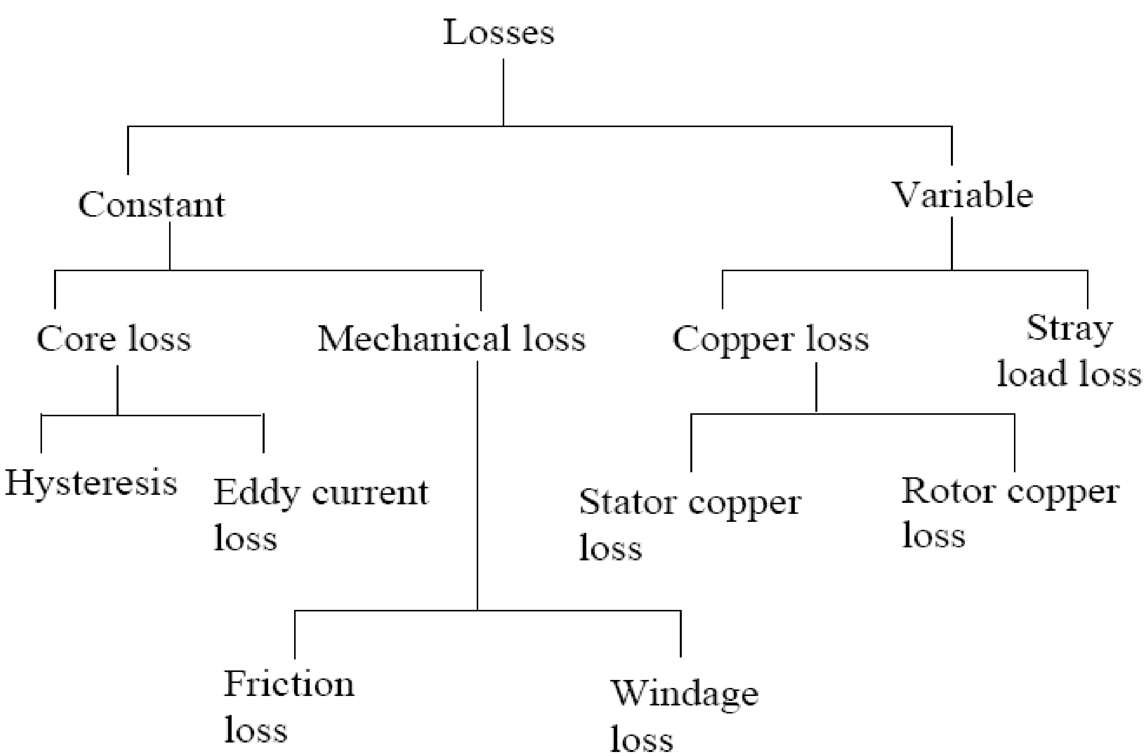

Fig (7) Losses in an Induction Motor

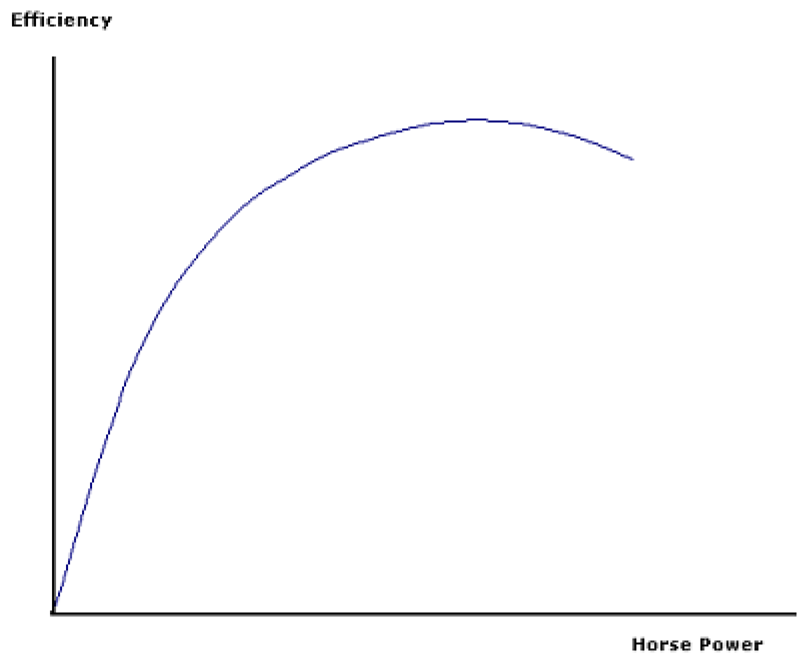

Fig (8) Efficiency curve of an Induction Motor

Procedure:

Measure the stator resistance of the Induction motor using digital multi-meter.

No Load Test: For the no load test run the motor without any load resistance (no resistance in the load bank). Measure the power input and line currents using the load manager. This will give stator copper loss and thus the fixed losses can be calculated.

Load Test: This test is performed at different loads. Start the motor under no load, load the motor in steps of 1kW up to 5 kW and note the shaft speed, power input and line currents in each case. Switch off the motor under no load after the experiment.

The motor output is calculated by subtracting losses from the input power. Losses consist of fixed losses, stator copper losses, rotor copper losses and stray losses. Fixed losses are calculated with the help of No Load test. Stator copper losses are calculated by line current and stator resistance. Rotor copper losses are calculated by multiplying the slip with air gap power of the motor (subtracting stator copper losses and fixed losses from input power gives the air gap power). Slip is calculated by the measurement of shaft speed. Stray losses are assumed to be 0.5% of the output power and this power accounts for air gap power, multiplied by slip gives the rotor copper loss.
For each loads calculate the motor efficiency and motor-generator system overall efficiency and plot graphs of motor efficiency and power factor against load.

Precautions:

- Do not overload the motor.
- Connection should be made carefully.
- Select proper range of voltage, current and power in load manager while taking readings.
- While measuring resistance(stator), make sure that it is cooled down to ambient temperature.
- While taking speed reading, be sure that reading is stable and synchronized.
- Timer must be set properly for load manager so that it can give stable reading.

Formulae:

Input power is given by,

$P_i = P_{core} + P_{friction\ windage} + P_{copper\ stator\ loss} + P_{copper\ rotor} + P_{stray\ loss} + P_o$

Assuming friction and windage losses to be negligible.

No Load Test:

$P_o = 0$

$P_{Cu,r} = 0$

$P_{Cu,stator}$ = Skin factor x 1.5 x I_L^2 x R_s Assume skin factor = 1.25

R_s = Effective resistance across stator

$P_{fixed\ losses} = P_i - P_{Cu,stator}$ (rotor losses are neglected in no load condition)

Assume $P_{core\ losses}$ = 75 % Fixed losses

Load Test:

For every load,

$P_{Cu,stator} = 1.25 \times 1.5 \times I_L^2 \times R_s$

Slip, $s = (N_s - N)/N_s$

N_s= synchronous speed=120*f/P [where P = 4 (no. of poles)]

$P_{Cu,rotor} = s\,(P_i - P_{Cu,stator} - P_{Core})$

P_{Core} = it is assumed to be equal to be .5% of the output.

Therefore, $P_o = \{P_i - (P_{fixed\ losses} + P_{Cu,stator} + P_{Cu,rotor})\}/1.005$

Efficiency (%)= (P_o/P_i)*100

Observation Table:

No	Load (kW)	Voltages (V)			Currents (A)			Power Input P_{in} (kW)	Power Factor PF	Speed N (RPM)	Slip s (%)	Constant Loss P_{fixed} (W)	Stator Cu Loss $P_{Cu,stator}$ (W)	Rotor Cu Loss $P_{Cu,rotor}$ (W)	Power Output P_o (kW)	Efficiency η (%)
		V_1	V_2	V_3	I_1	I_2	I_3									
1	0															
2	1															
3	2															
4	3															
5	4															
6	5															

Error Analysis:
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Results:

Conclusions: