

Measurements executed on the CWD 49 D pump provided with a PVC tube around the raising main to limit shockforces

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Measurements executed on the CWD 49 D pump
provided with a PVC tube around the
raising main to limit shockforces

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April 1988

R 914 D

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1. INTRODUCTION

The CWD 49 D pump has been designed to be coupled in the first instance to the CWD 2000 mill. Design calculations for this pump have been made in TUE internal note 06-88 of A. Kragten. In this note the maximum allowable pump rod force has been calculated to be 1500 N. The most critical part in the transmission is the rotor shaft if it is made of Fe 37.

It was expected that it should be possible to limit the pump rod force sufficiently if the 2" raising main is provided with holes in the bottom part and a PVC tube around it. (See drawing E 8711-00.)

The influence of the size and numbers of holes and the length of the tube has been investigated for the most unfavourable situation which can occur if the pump is coupled to the CWD 2000 mill. It is supposed that this most unfavourable situation occurs if the pump is mounted on the maximum depth below ground level being 18 meters, if the stroke is maximum being 0,1 meters and if the rotor speed is maximum being about 2.8 rps. The effect of elasticity due to the length of the pump rod can not be simulated.

Under the most unfavourable conditions the pump rod has a length of about 24 meters but the length of the pump rod in the test rig is only 5 meters so the shockforces measured on the test rig can be expected to be larger than under field conditions. The last two series of measurements have been executed to simulate the use of the CWD 49 D pump under the CWD 2740 mill. After finishing the test with a normal piston valve the pump has been equipped with a floating valve. These tests will be described in a separate report.

2. DESCRIPTION OF THE TEST STAND (see fig. 1)

The pump test rig (see description in report 813 A) provides an oscillating guided and sealed stainless steel rod ϕ 16 to which the pump rod can be coupled.

The stroke can be adjusted continuously from 0 up to 200 mm and the speed of the crank rod from 0 up to 2.6 rps.

The force in the pump rod is measured with a force transducer type: E. Brosa + 10 KN and the velocity of the pump rod is measured with a velocity transducer type: Schaevitz 7L10VT-Z

The flow is measured with an inductive flow meter: Flowtec D1 651 speed mag Endress + Hauser. The water level in the pressure vessel is kept constant automatically by means of a float steered valve.

The pressure in the pressure vessel can be adjusted on a certain level.

The static water head between the water level in the drum in which the pump hangs and the water level in the pressure vessel is about 4.5 meters.

The pressure in the pressure vessel was taken at 2 bar for the first series of measurements so the total water head is about $4.5 + 9.8 \cdot 2 = 24.1$ meters.

The total length of the 2" gaspipes from the pump to the bunch of 1 1/4" pipes is about 7 meters. The total length of the bunch of pipes is about 9 meters. The inside area of a 1 1/4" pipe is about 0.5 the inside area of a 2" pipe.

Shockforces and acceleration forces are inversely proportional to the inside area of the pipe. So 9 meters 1 1/4" pipe is about equivalent to 18 meters 2" pipe.

So totally $7 + 18 = 25$ meters 2" gas pipe have been simulated. Although the watermass is simulated well the pressure drop due to pipe friction is much larger than for a 2" pipe.

To simulate the behaviour of the pump if coupled on the CWD 2740 mill the last two series of measurement have been done with a pressure in the pressure vessel of 4.5 bar resulting in a total head of $4.5 + 9.8 \times 4.5 = 48.6$ meters.

The bunch of pipes has been lengthened with 12.5 meters 1 1/4" pipe resulting in a total simulated 2" pipe length of about 50 meters.

The PVC tube around the 2" raising main originally had a length of four meters. The effective length could be adjusted by changing the position of the upper hose clamp.

From measurement P04910 on, the length of the PVC tube is 1.45 meters and there is a 2" socket in the 2" raising main at a distance of 1.5 meters above the pump.

Because of the heavy flywheel in the transmission of the test rig it takes a long time to adjust a certain pump speed. Therefore the knob with which the motor speed is adjusted has been provided with ten mark lines being A to J.

The knob is put on a certain mark line and the time of one revolution of the crank shaft is measured after stabilising of the rotational speed. To measure one revolution the crank shaft is provided with a disk in which one slit has been made which is detected by a photocel. The position of the slit corresponds with the lowest dead centre of the piston.

For most measurements mark lines A, B, D, F, H and J have been used.

Mark line J corresponds with the maximum speed of the crank shaft resulting in $T \approx 0,39$ s or $n \approx 2,55$ rps.

The data acquisition was done with a IBM XT personal computer equipped with a Metrabyte Dash-16 data acquisition board and Intel 8087 Math co-processor and a Hercules graphics card.

To collect and process data use was made of the scientific software package ASYST.

The accuracy of the components of the measuring system are:

force transducer:	- linearity 0.15%
	- hysteresis 0.15%
amplifier for force transducer	$\pm 2\%$
speed transducer	$\pm 1\%$ of output
flow transducer	$\pm 1\%$ of maximum flow range

The accuracy of the analog to digital conversion is:

-10 V \rightarrow 0 bits	} + 0.005 V
+10 V \rightarrow 4096 bits	

3. DESCRIPTION OF THE MEASURED CONFIGURATIONS

To all measurements a code number has been given which is used to store the measurements on the disk of the computer.

The first part of the code number is P049, referring to the CWD 49 D pump. Then a number follows referring to a certain configuration of PVC tube length and numbers and size of holes in the 2" raising main.

Then a letter follows referring to the mark line of the knob with which the motor speed is adjusted.

If a certain speed has been measured more than once a number is added to distinguish the different measurements.

Configuration 1 (measurements P049 1A → J).

The pump has been measured without the PVC tube around the 2" raising main (and without holes in the pipe) and without a starting groove in the piston. The stroke $s = 100$ mm. The pressure in the pressure vessel $P_{pv} = 2$ bar. The head $H = 24.1$ m.

Configuration 2 (measurements P049 2A → J1 and P049 2A₁ → A₁₀).

As configuration 1 but now a V shaped starting groove with width 2.5 mm has been made in the piston. All next measurements have been executed with this starting groove. Measurements P049 A₄ → A₁₀ have been executed with the lowest reduction ratio of the V belt variator.

Configurations 3 → 8 (measurements P049 3A → 8J and P049 3J1 → 8J1)

18 holes $\phi 15$ mm have been drilled in the lowest halve meter of the 2" rising main and a series of measurements have been executed for six different tube length each at six different speeds.

From now on the V belt variator has been put on the highest reduction ratio again.

configuration 3 means tube length = 0,5 m

" 4 " " " = 1 m

" 5 " " " = 2 m

" 6 " " " = 3 m

" 7 " " " = 4 m

" 8 " " " = 1,5 m

Unfortunately later on it has been found that something must have been wrong with the functioning of the piston valve because the shockforce was

much too low. Probably some iron curls coming from drilling the holes have been clamped between the valve and the valve stop making the valve gap very small. All these measurements have been cancelled.

Only for the maximum speed configuration 3 → 8 have been measured again (measurements P049 3J1 → 8J1).

Configuration 9 (measurements P049 9A → J1)

18 more holes ϕ 15 mm have been added so there are 36 holes ϕ 15 mm in the lowest meter of the 2" rising main. Tube length is 1.5 meters.

Configuration 10 (measurements P049 10A → J1)

The raising main has been provided with a new piece 2" gas pipe in which four holes ϕ 20 mm have been drilled in the lowest 0.15 meter. The PVC tube has been shortened to 1.45 meter.

Configuration 11 (measurement P049 11J1)

As 10 but now the effective tube length is 1 meter.

Configuration 12 (measurement P049 12J → J1)

tube length = 1.15 meter.

Configuration 13 (measurement P049 13 J1)

tube length = 0.5 meter.

Configurations 14 → 20 (measurements P049 14J → 20J)

A series of seven different tube lengths have been measured sequentially.

configuration 14 means tube length = 0,25 m

" 15 " " " = 0,5 m (identical to conf. 13)

" 16 " " " = 0,75 m

" 17 " " " = 1 m (identical to conf. 11)

" 18 " " " = 1,15 m (identical to conf. 12)

" 19 " " " = 1,25 m

" 20 " " " = 1,45 m (identical to conf. 10)

Configuration 21 (measurements P049 21A → J1)

Out of the previous series of measurements it has been found that 1 meter is the optimal tube length.

This length has been measured for six speeds.

Configuration 22 (measurements P049 22J)

Now the bunch of tubes has been disconnected and the water has been pumped into a drum placed near the ceiling of the laboratory. The inside diameter of the pipe to the drum is 48 mm. The total static head now is about 10.3 meters.

Configuration 23 (measurement P049 23J)

The bunch of tubes has been connected again.

The pressure in the pressure vessel has been taken $P = 1.5$ bar.

To check the influence of the PVC tube and the rising main partially filled with air, the following has been done.

The exhaust tube which normally is placed not directly in the drum but in a piece of pipe, to facilitate the escape of air bubbles, now has been kept close to the pump just above the water level. Therefore a lot of air is blown in the water and sucked by the pump (measurement P049 23J1).

Configuration 24 → 27 (measurements P049 24J → 27J).

All air has been removed out of the PVC tube and four different pressures in the pressure vessel have been taken.

configuration 24 means $P = 1$ bar

" 25 " $P = 3$ bar

" 26 " $P = 4$ bar

" 27 " $P = 5$ bar

Configuration 28 (measurements cancelled)

Configuration 29 (measurements P04929A→J)

$P = 4.5$ bar resulting in $H = 48.6$ meters.

12.5 meters 1 1/4" pipe have been added to the bunch of pipes resulting in a simulated pipe length of about 50 meters.

2" gas pipe

Length of PVC tube is 1.45 meters.

Configuration 30 (measurements P04930A→J)

Identical to 29 except length of PVC tube is 1 meter.

In the following chapter some elucidation is given to the graphs which have been made by the computer. Not all measurements have been mentioned.

4. ELUCIDATION OF THE MEASUREMENTS

4.1 General

For each measurement (a certain configuration measured at a certain speed) the computer has made graphs of the following quantities as a function of the time: 1e pump rod force, 2e flow, 3e piston velocity, 4e piston position.

As time, the time required for two revolutions has been taken. Every graph is printed on one sheet A4 format. The whole set of graphs of all measurements has a thickness of some cm so it is not practical nor necessary to mention them all in this report.

A selection of the graphs for the two most interesting quantities being force and flow has been given in annex I Measured F-t and q-t curves. The F-t and q-t curves have been composed on one A4 format.

On the graph of the first measurement of a series of measurement some special information is given about the configuration like, starting groove, pressure, height, etc.

If nothing is mentioned this means that the configuration has not been changed and that the information on the previous graph is still valid.

For measurements P049 1A → J P049 2A → J1 and P049 21A-J the difference between maximum and minimum force, the mechanical and the volumetrical efficiency have been given as a function of the rotational speed in annex II $F_{\max} - F_{\min}$, η_{vol} , η_{mech} as a function of n.

For all F-t curves and for the $(F_{\max} - F_{\min})$ -n curves the static pump rod force F_{stat} has been reproduced as a thick horizontal line.

F_{stat} has been calculated with the formula:

$$\left. \begin{aligned} F_{\text{stat}} &= \rho \cdot g \cdot H \cdot \frac{\pi}{4} (D_p^2 - d^2) \\ \rho &= 1000 \text{ kg/m}^3 \\ g &= 9.81 \\ D_p &= \text{piston diameter} = 0.049 \text{ m} \\ d &= \text{pump rod diameter testing} = 0.02 \text{ m} \end{aligned} \right\} F_{\text{stat}} = 15.42 \text{ H (N)}$$

For the discription of the configuration for each measurement see chapter 3.

4.2 Elucidation of some measurements

0049 1A → J

At the lowest speed the flow is so small that the signal is overruled by noise.

At $n = 1,613$ there is a double peak in the F-t curve for which no good explanation is found. At the maximum speed of the test rig the peak force is 2168 N so too high for the CWD 2000 rotor shaft. The mechanical efficiency is good (0.7)

P049 2A → H + 2J1 + 2A3 → 2A7

At the lowest speed the F-t curve is not symmetrical. Later on this appeared to be caused by fluctuations in the rotational speed of the test rig because the V belt variator had been placed on the highest ratio.

In measurements P049 2A3 → 2A7 the V belt variator had been placed on the lowest ratio resulting in a motor speed of about a factor eight higher. Because of the flywheel effect of the motor now the speed is about constant resulting in a symmetrical patron of the F-t curve also at very low speeds. At speeds lower than about 0.05 rps the static pump rod force is not reached because all the water leaks away through the starting groove.

The maximum force at maximum speed for a pump with a starting groove is somewhat lower than without a groove. It is very strange that there is such a large difference for $n = 1,6$ rps between the piston with and without a starting groove.

The mechanical efficiency is lower than for a pump with no starting groove but for higher speeds it goes to 0.7 too.

P049 3J1-8J1

In this series of measurements the tube length has been varied to find the optimum length. A minimum has been found for a tube length of 1 meter ($F_{\max} = 935$ N). The shockforce is about the same as the force at $t = 0,1$ s. For a tube length of 4 meters again a low maximum force is found ($F_{\max} = 979$ N) but now the shockforce is much lower than the force at $t = 0,1$ s. Especially for a long tube length the shape of the q-t curve becomes about siniodical and during apart of the time the flow becomes negative. Probably this indicates resonance of the PVC tube. Because a short tube is cheaper than a long one the next measurements only have been executed with relative short tube lengths.

P049 9J

Adding another 18 holes appeared to have no effect.

(compare P049 8J1 with P049 9J)

Probably lesser holes are allowed.

P049 14J → 20J

Because making the holes in the 2" raising main is a lot of work and because they are difficult to round off at the inside a new raising main had been made with only four holes ϕ 20 in the lowest 0,15 meter of the raising main. The PVC tube had been shortened to 1.45 meters.

Also for this hole pattern 1 meter tube length appeared to give the lowest maximum force at maximum speed.

P049 21A → J

For the optimum tube length of 1 meter six speeds have been measured.

The maximum force for maximum speed appeared to be somewhat larger than for 18 holes ϕ 15 but the shockforce is much lower than the force at $t = 0.1$ s. (compare P049 4J1 with P049 21J).

An overview of $F_{\max} - F_{\min}$, η_{mech} and η_{vol} has been given in annex II.

The influence of the tube on the maximum force is very strong. The maximum forces for different speeds appear to lay on an almost straight line.

The tube also has a positive influence of the mechanical efficiency at moderate speeds.

It can be seen that $\eta_{\text{mech}} > 0.7$ for $n > 1$ rps and that η_{vol} becomes higher than 1 for $n > 1.5$ rps.

P049 22J

This measurement was done to prove that the pump rod force really decreases for a lower head (10.3 meters) than the simulated head of 24.1 meters in the previous measurements.

P049 23J1

This measurement shows that air in the gap between the 2" rising main and the PVC tube and in the rising main itself has a positive influence on the maximum force. The situation of air in the gap between the PVC tube and the rising main exists just after mounting of the pump in the well before all air has been dissolved in the water.

Because of the large amount of air bubbles passing through the flow meter the q-t curve has a very freakish shape. The accuracy of the flow meter is low resulting in an unrealistic high mechanical efficiency of 1.288.

P049 23J → 27J

These measurements have been done to see the influence of only changing the pressure in the pressure vessel. These configurations can not occur in reality because normally both pressure and pipe length change in the same way.

If the measurements for 3, 4 and 5 bar are compared it can be seen that the shockforces are almost the same but that the curves differ maximal at about 0.1 s.

P049 29A → J

The CWD 49 D pump also has been tested under conditions which may occur if it has been coupled to the CWD 2740 mill. Because of the larger rotor diameter the pump can be mounted on a maximum depth of about 50 meters. With $P_{pv} = 4,5$ bar a head of about 48.6 meters has been simulated. Also the water mass has been increased by adding another 12.5 meters 1 1/4" gas pipe. For this higher pressures a tube length of 1.45 m resulted in a lower maximum force than a tube length of 1 m (compare P049 29J with P049 30J). For the tube length of 1.45 meters six speeds have been measured.

The shockforce due to closure of the piston valve is relatively small but there is a larger negative peak due to closure of the foot valve.

In internal note 06.88 of A. Kragten we found that the maximum allowable force for the pump rod is 2356 N if we could take $R=0$ but because of the large negative peak taking $R=0$ is not allowed. This means that problems with fatigue can be expected. Maybe this can be compensated because in reality we will have a much longer pump rod in the field than in the test rig.

P049 30J

The F-t curve goes out of the range of the F-axis. The real maximum force is 3062N which is much larger than for a tube length of 1.45 m.

5. CONCLUSIONS

- 5.1 It appeared to be possible to decrease the maximum force with about a factor two by using an elastic element formed by a PVC tube of 1 meter length clamped around a raising main which has been provided with four holes ϕ 20 mm.
- 5.2 The volumetric efficiency η_{vol} becomes higher than 1 for $n > 1.5$ which causes a higher output at high wind speeds.
- 5.3 The mechanical efficiency η_{mech} is good (about 0.7).
- 5.4 A starting groove results in a small decrease (about 10%) of the maximum force at maximum speed.

6. RECOMMENDATIONS

- 6.1 It is recommended to test the pump on the 5001 pump test rig with the original pump rod length to investigate the influence of a more elastic pump rod on the shockforce.
- 6.2 It is recommended to test the PVC tube under a fluctuating pressure to investigate the fatigue strength.

ANNEX I

Measured F-t and q-t curves

Presented are:

P049 1A → J

P049 2A → H + 2J1 + 2A3 → 2A7

P049 3J1-8J1

P049 9J

P049 14J → 20J

P049 21A → J

P049 22J

P049 23J1

P049 23J → 27J

P049 29A → J

P049 30J

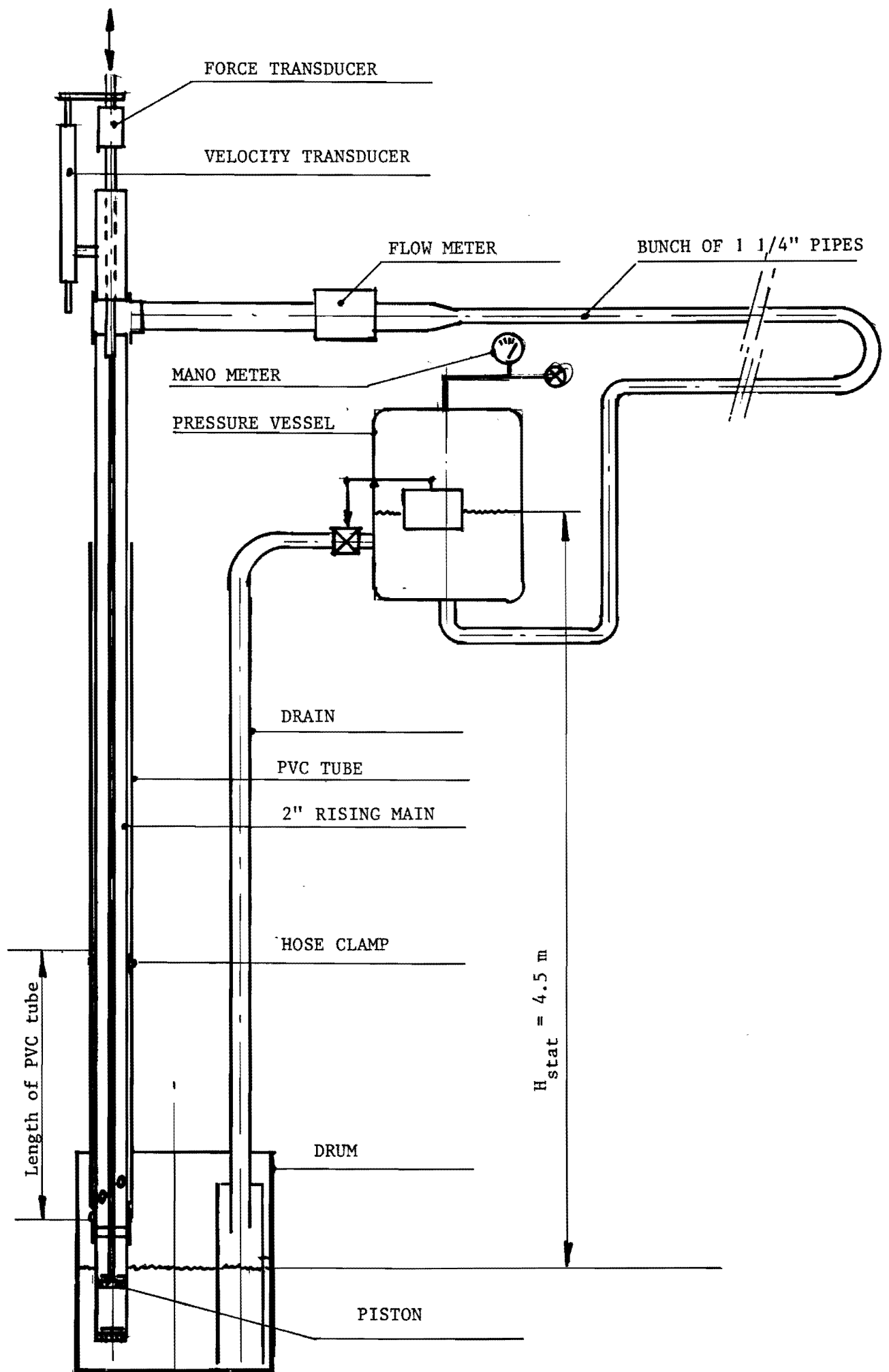
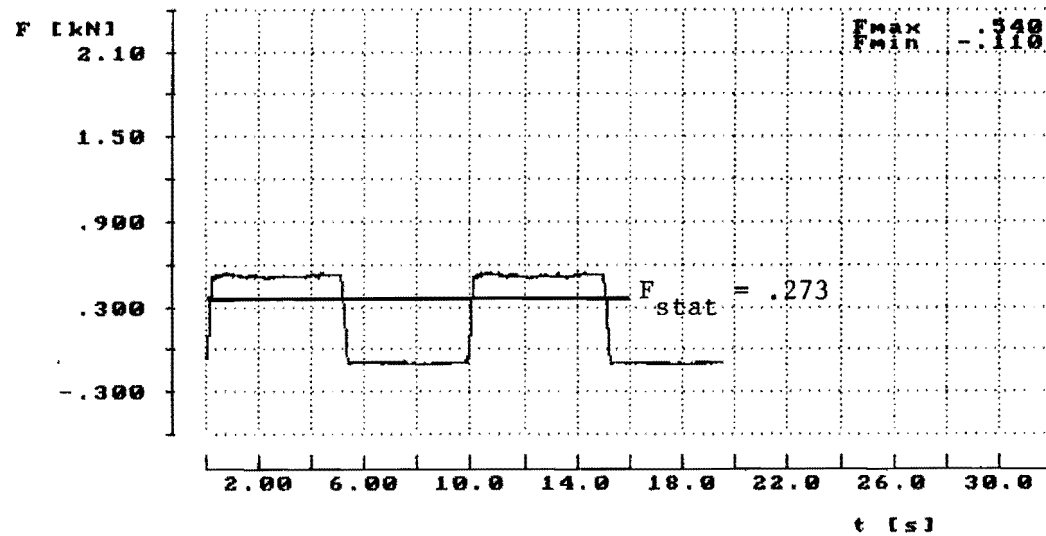


FIG. 1



filename --> B:P0491A._

no starting groove

no PVC tube

$P_{pv} = 2$ bar

$H = 24.1$ m

Pin [W]:

6.310

Pout[W]:

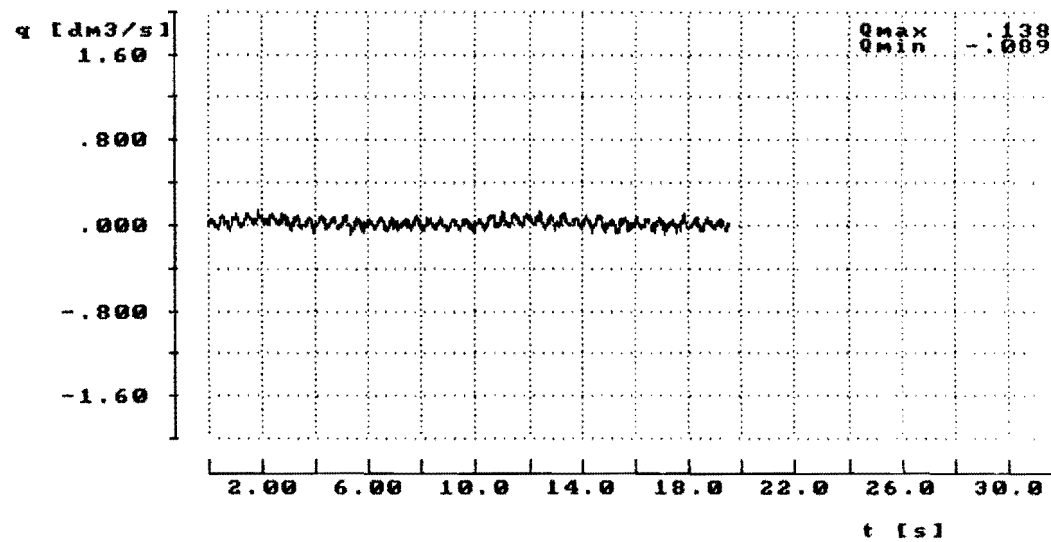
4.375

Evol :

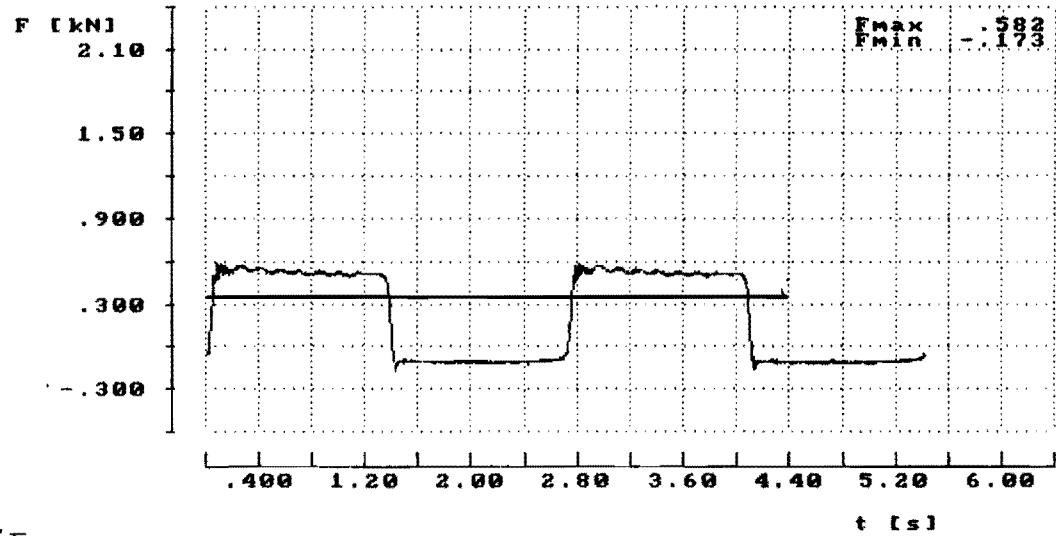
.958

Emech :

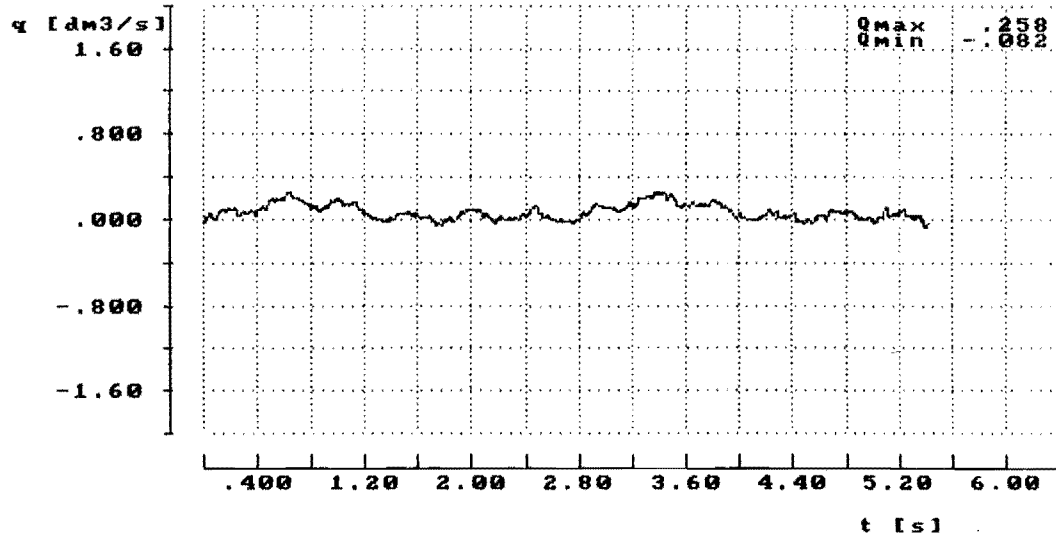
0.693



rotationspeed (rps): .102 number of rotations : 2.000
 meanflow (dm³/s) : .019 sample frequency (Hz): 102.459



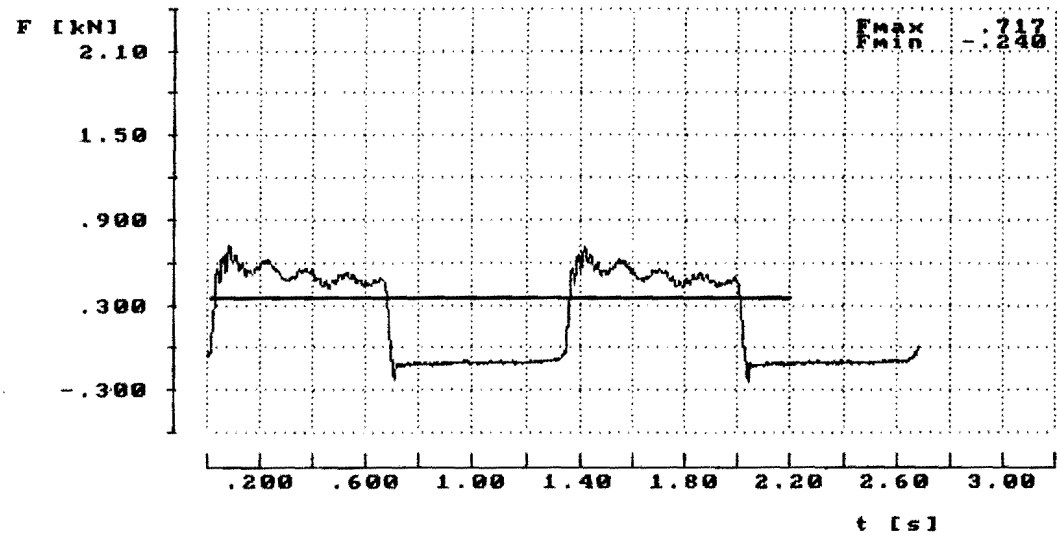
filename --> B:P0491B._



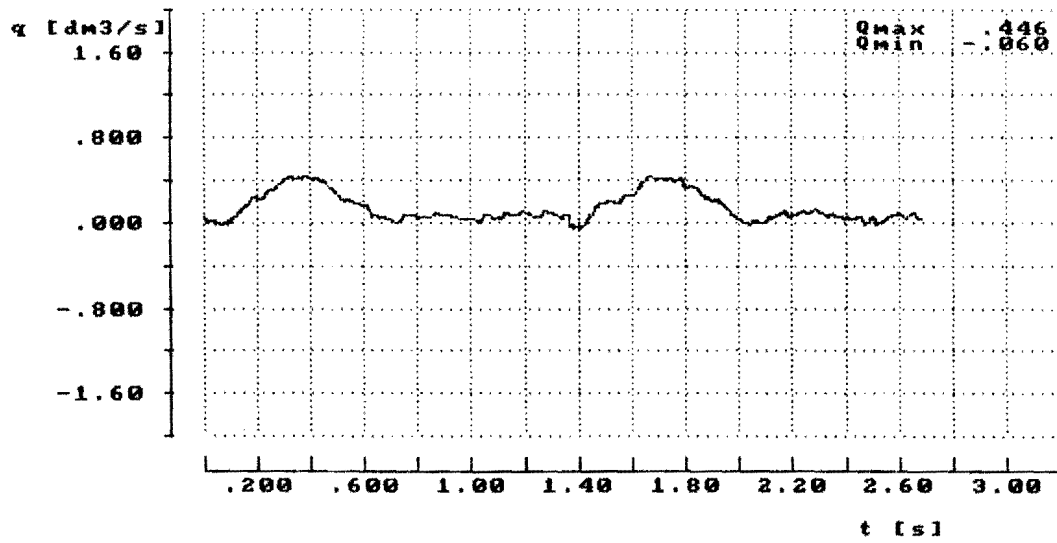
Pin [W]:
 23.104
Pout[W]:
 16.214

Evol :
 .986
Emech :
 0.696

rotationspeed (rps): .369 **number of rotations :** 2.000
meanflow (dm3/s) : .069 **sample frequency (Hz):** 369.004



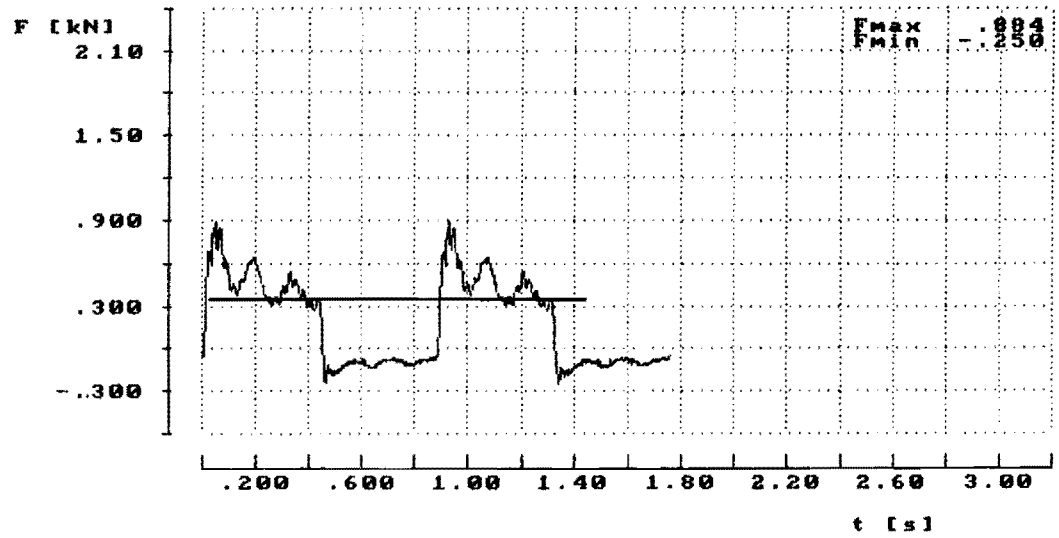
filename --> B:P0491D._



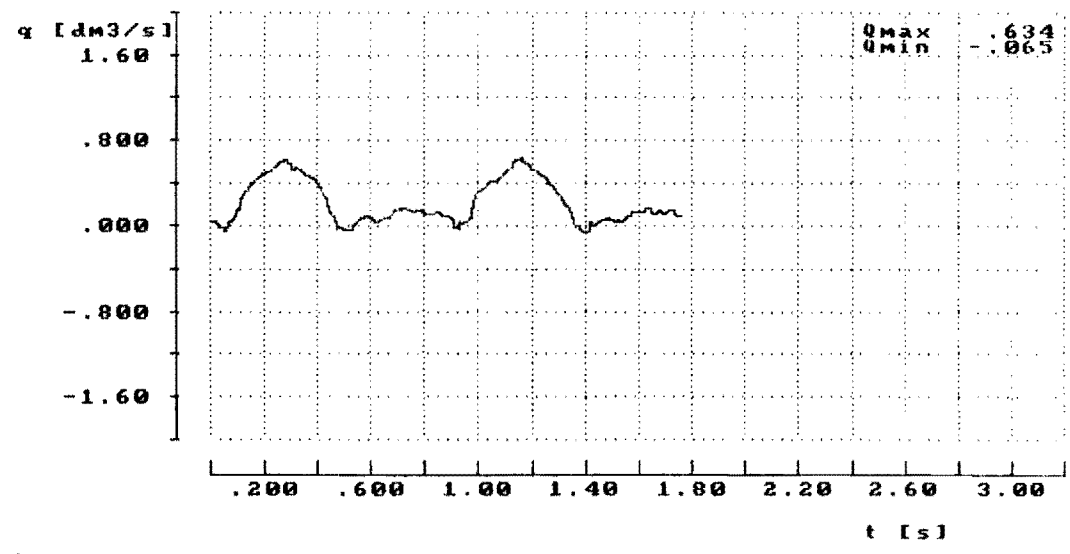
Pin [W]:
46.645
Pout[W]:
32.823

Evol :
.987
Emech :
0.703

rotationspeed (rps): .746 number of rotations : 2.000
meanflow (dm3/s) : .139 sample frequency (Hz): 746.269



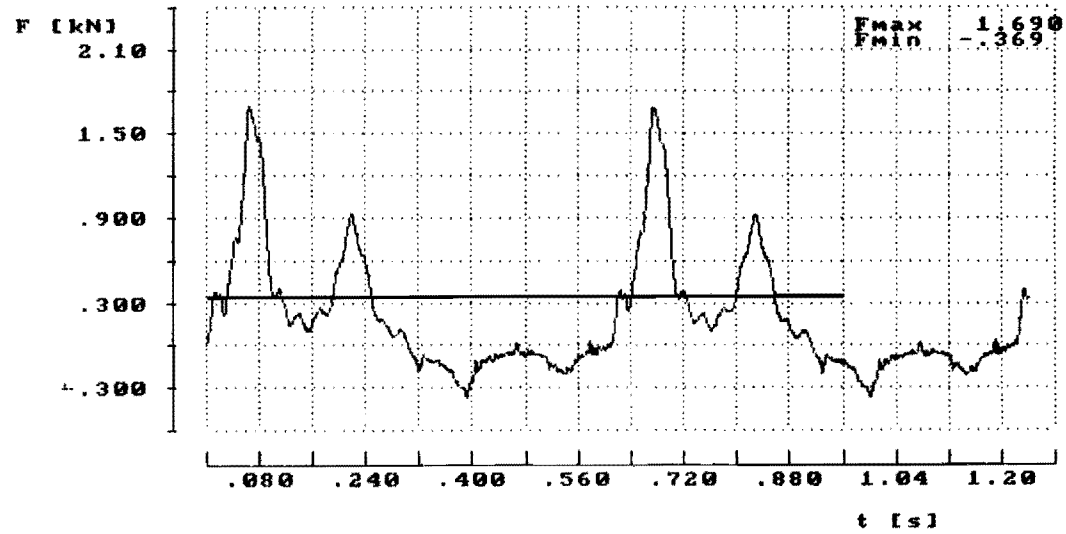
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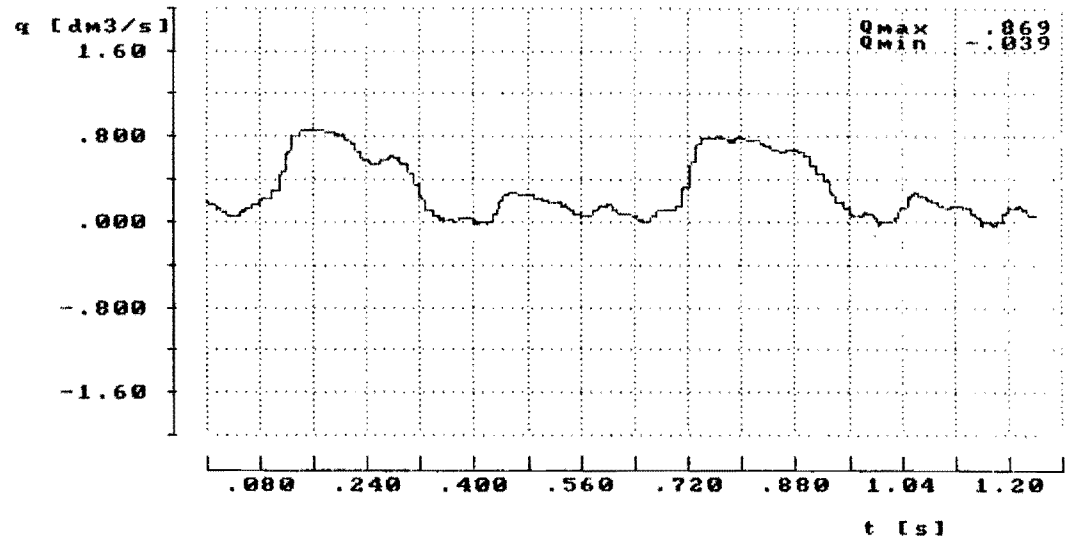
Pin [W]:
65.463
Pout [W]:
51.426

Evol :
1.015
Emech :
0.786

rotationspeed (rps): 1.136 number of rotations : 2.000
meanflow (dm3/s) : .218 sample frequency (Hz): 1136.364



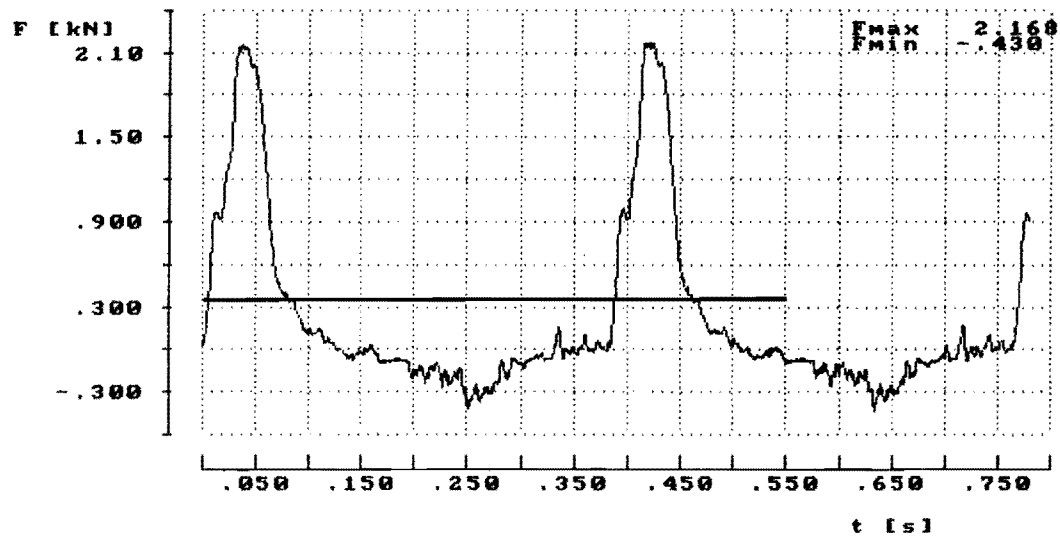
filename --> B:P0491H._



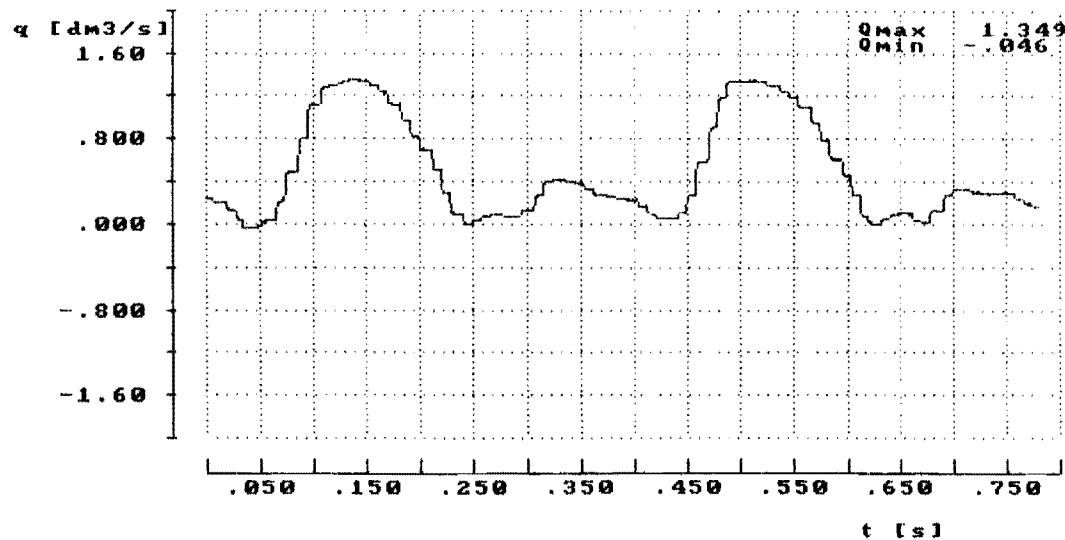
Pin [W]:
100.552
Pout[W]:
72.444

Evol :
1.007
Emech :
0.720

rotationspeed (rps): 1.613 number of rotations : 2.000
meanflow (dm3/s) : 0.306 sample frequency (Hz): 1612.903



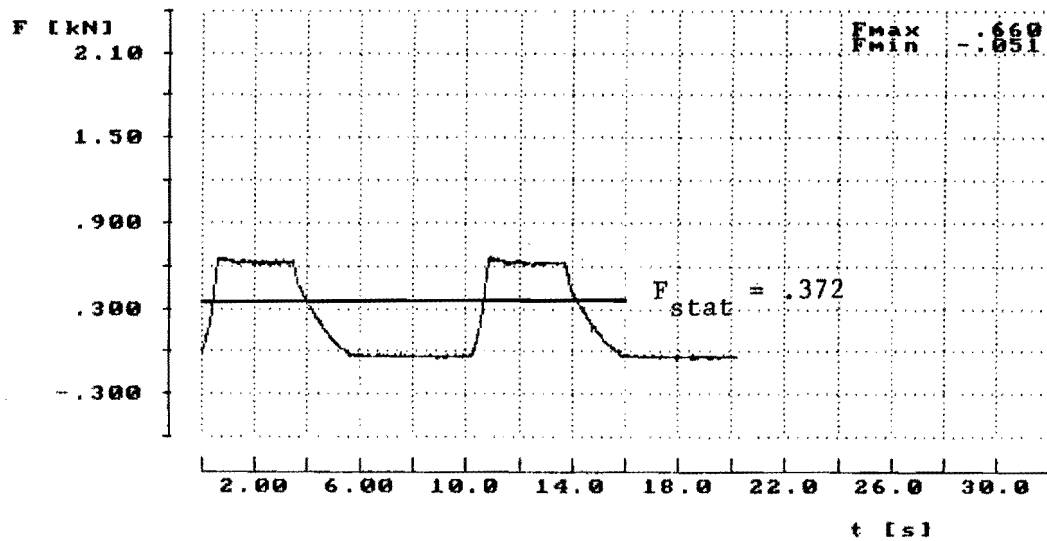
filename --> B:P0491J._



Pin [W]:
 168.684
Pout[W]:
 116.886

Evol :
 1.022
Emech :
 0.693

rotationspeed (rps): 2.564 **number of rotations :** 2.000
meanflow (dm3/s) : .494 **sample frequency (Hz):** 2564.103



filename --> B:P0492A...

with starting groove

no PVC tube

$P_{pv} = 2$ bar

$H = 24.1$ m

P_{in} [W]:

5.892

P_{out} [W]:

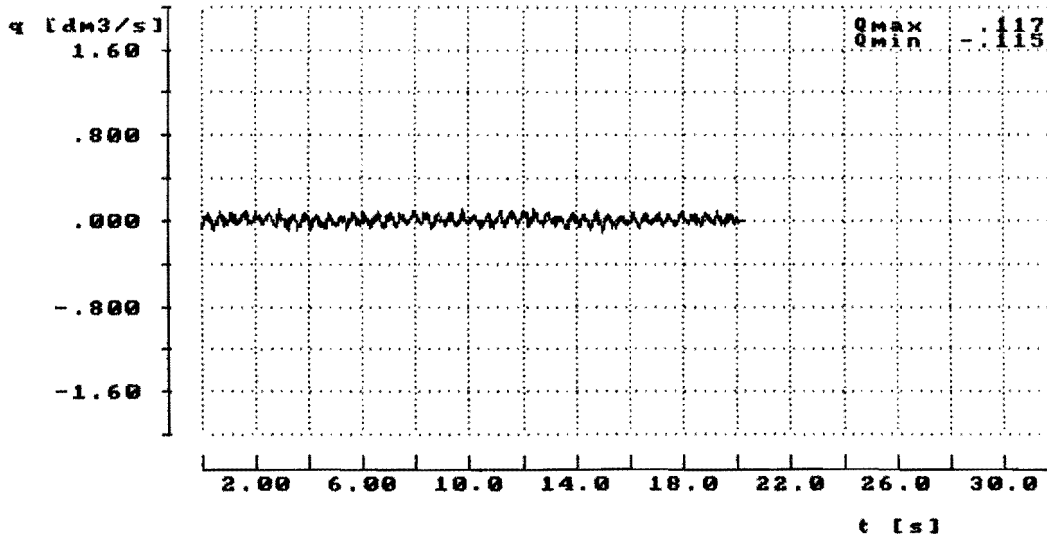
1.009

E_{vol} :

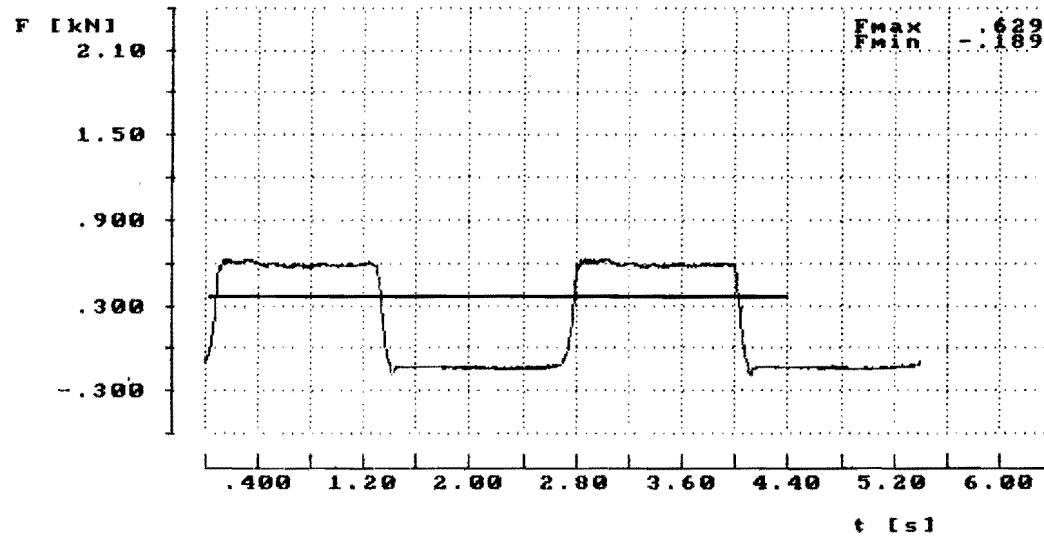
.228

E_{mech} :

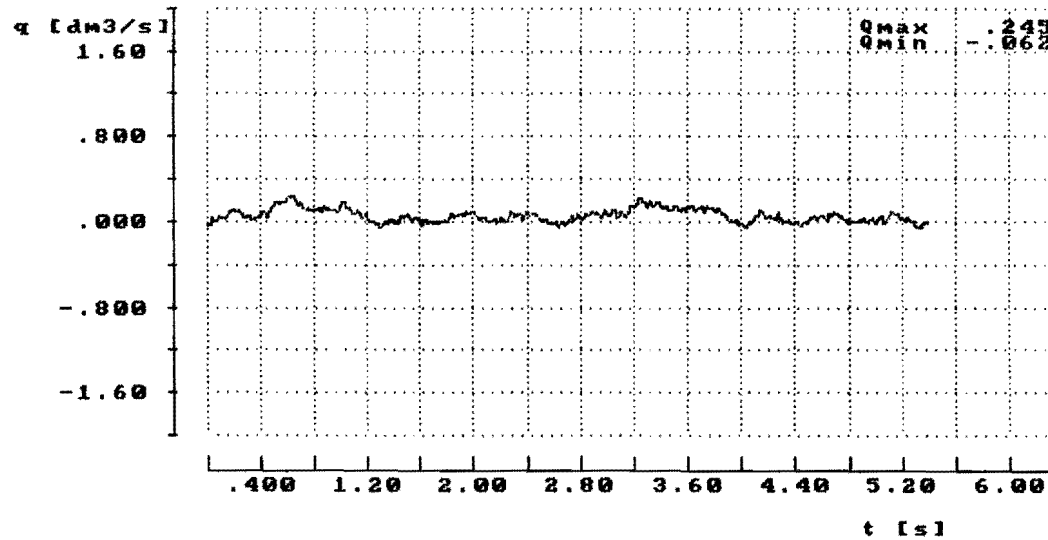
0.171



rotationspeed (rps): .099 number of rotations : 2.000
 meanflow (dm3/s) : .004 sample frequency (Hz): 99.108



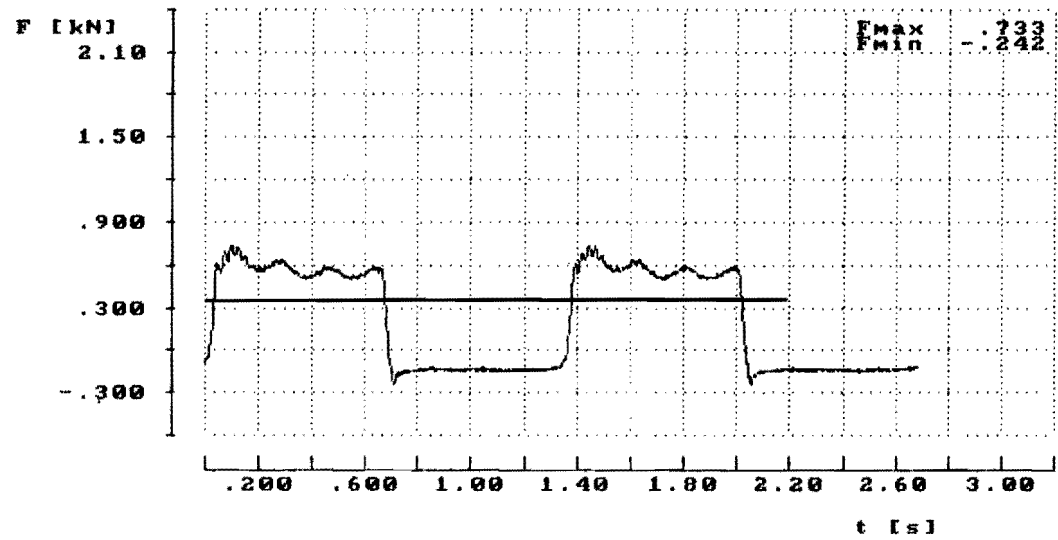
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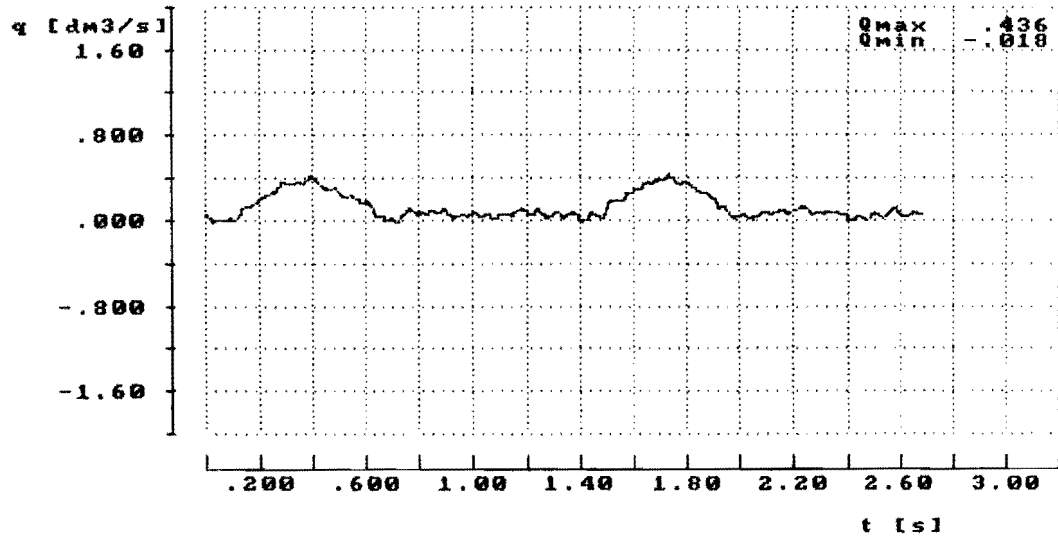
Pin [W]:
26.724
Pout[W]:
13.043

Evol :
.790
Emech :
0.488

rotationspeed (rps): .370 number of rotations : 2.000
meanflow (dm3/s) : .055 sample frequency (Hz): 370.370



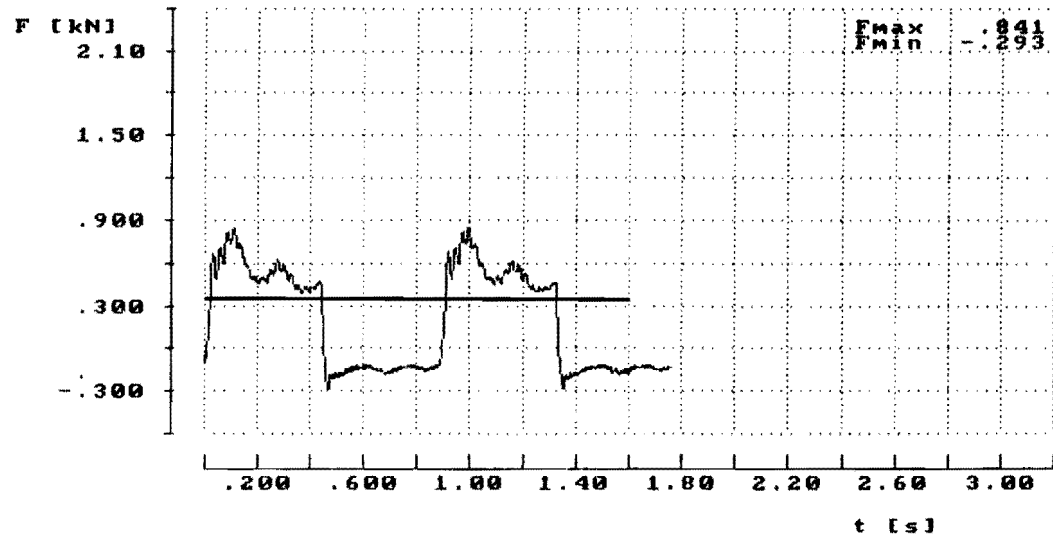
filename --> B:P0492D._



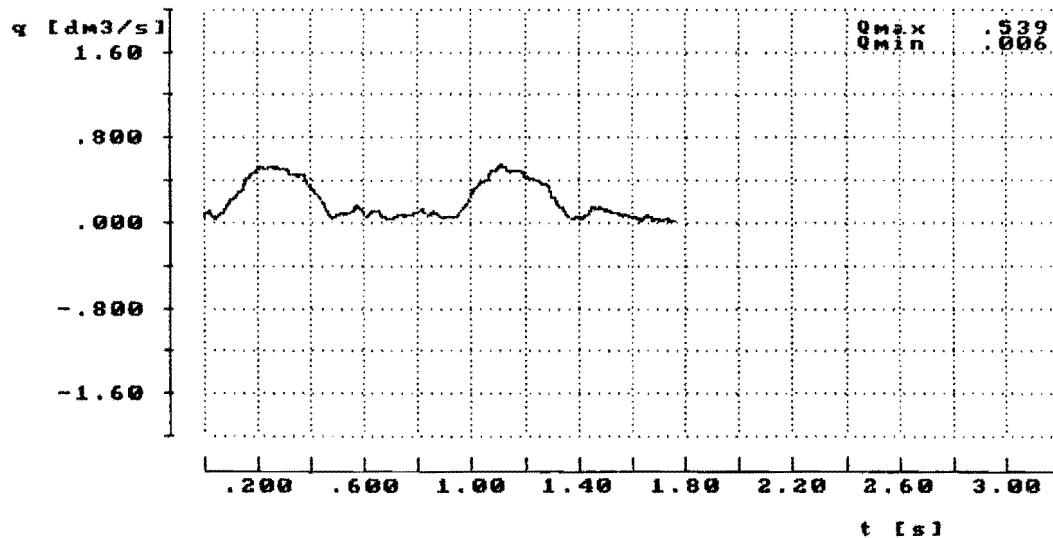
Pin [W]:
52.916
Pout[W]:
30.010

Evol :
.902
Emech :
0.567

rotationspeed (rps): .746 number of rotations : 2.000
meanflow (dm3/s) : .127 sample frequency (Hz): 746.269



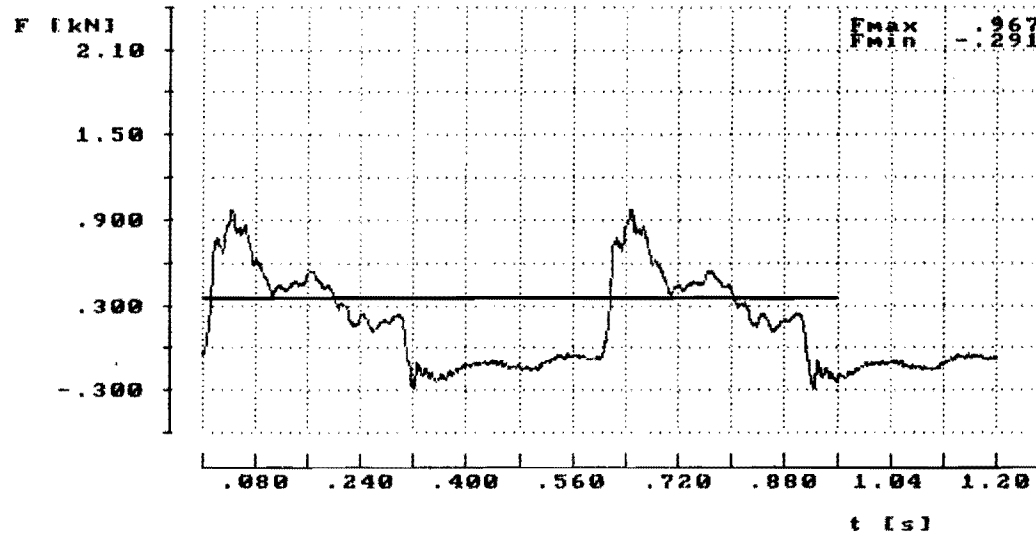
filename --> B:P0492F._



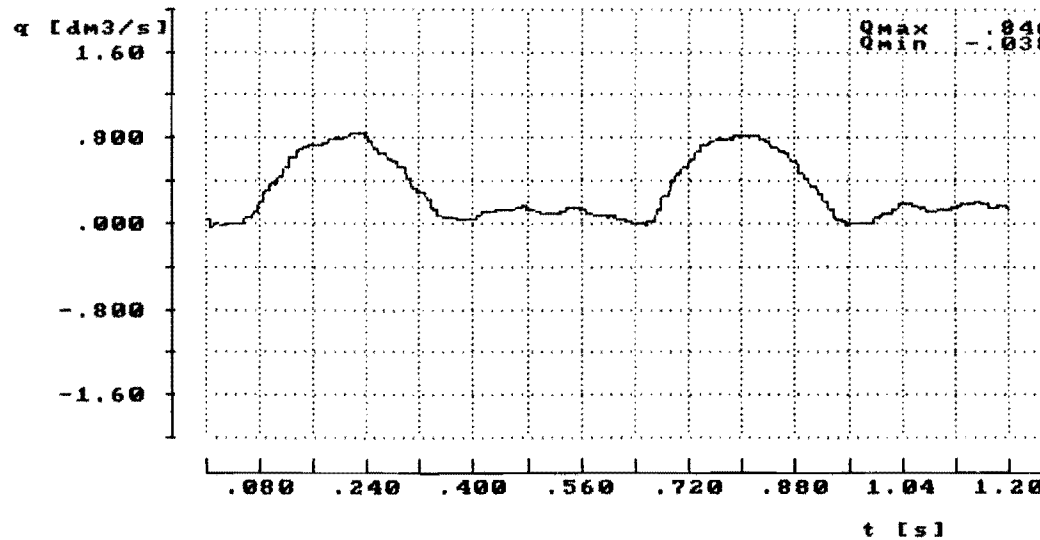
Pin [W]:
80.076
Pout[W]:
49.051

Evol :
.968
Emech :
0.613

rotationspeed (rps): 1.136 number of rotations : 2.000
meanflow (dm3/s) : .207 sample frequency (Hz): 1136.364



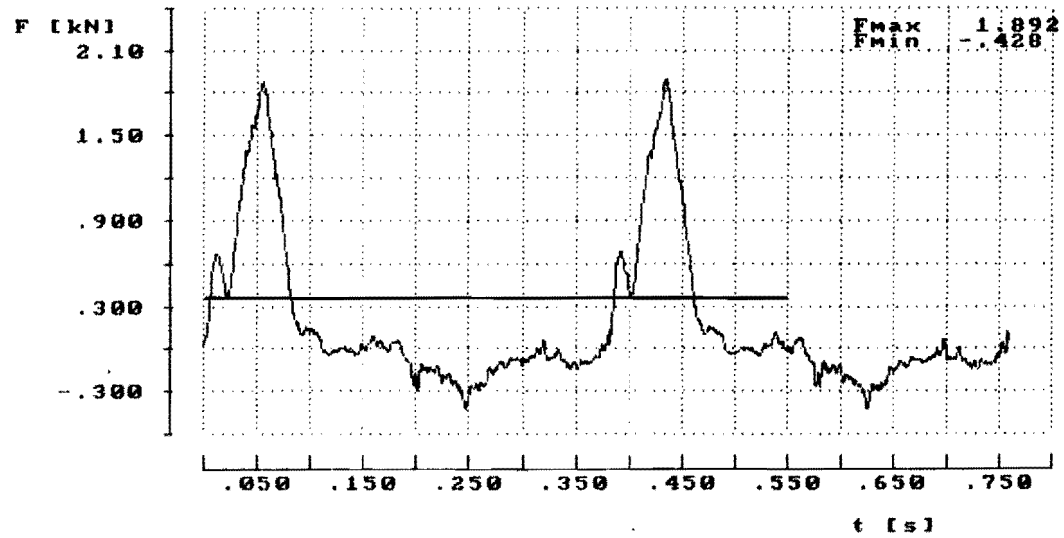
filename --> B:P0492H._



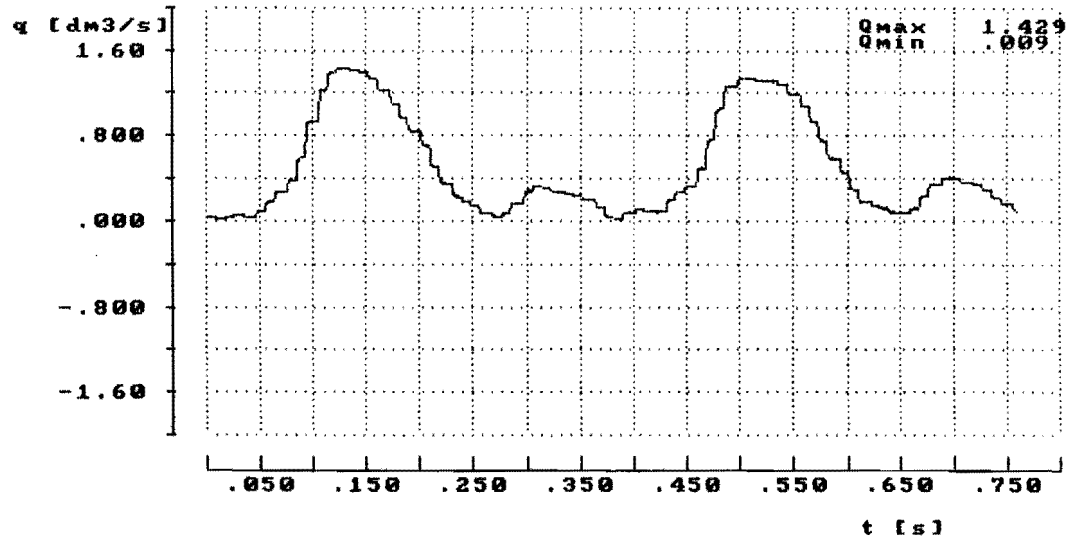
Pin [W]:
95.540
Pout[W]:
72.039

Evol :
.974
Emech :
0.754

rotationspeed (rps): 1.667 number of rotations : 2.000
meanflow (dm3/s) : .306 sample frequency (Hz): 1666.667



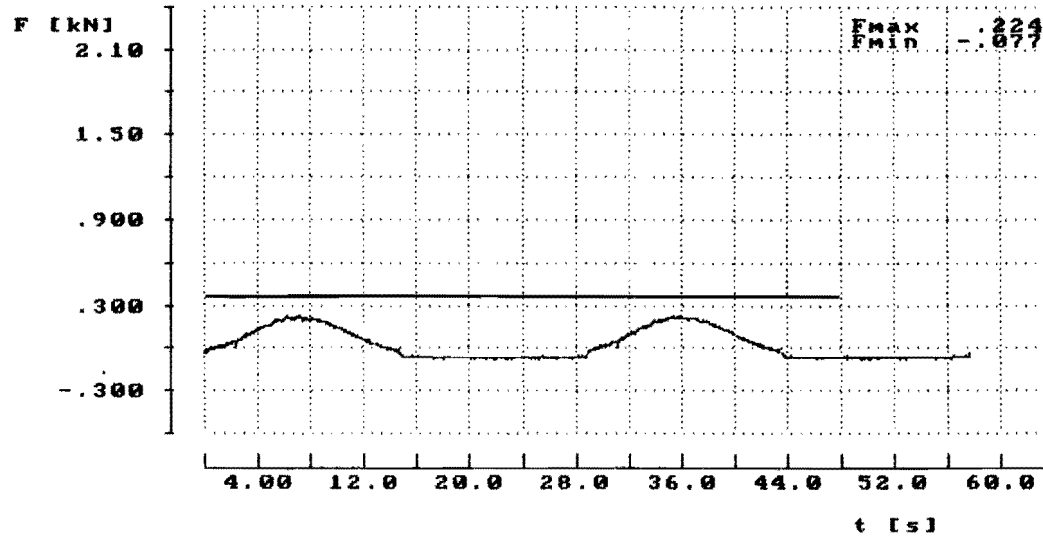
filename --> B:P0492J1._



Pin [W]:
 164.873
Pout[W]:
 117.573

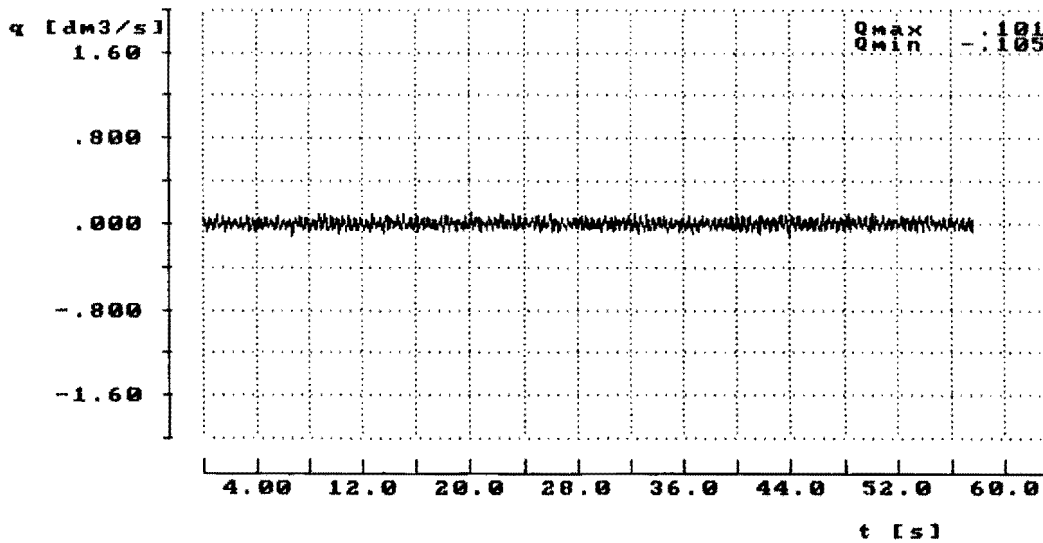
Evol :
 1.006
Erech :
 0.713

rotationspeed (rps): 2.632 **number of rotations :** 2.000
meanflow (dm3/s) : .499 **sample frequency (Hz):** 2631.579



filename --> B:P0492A5._

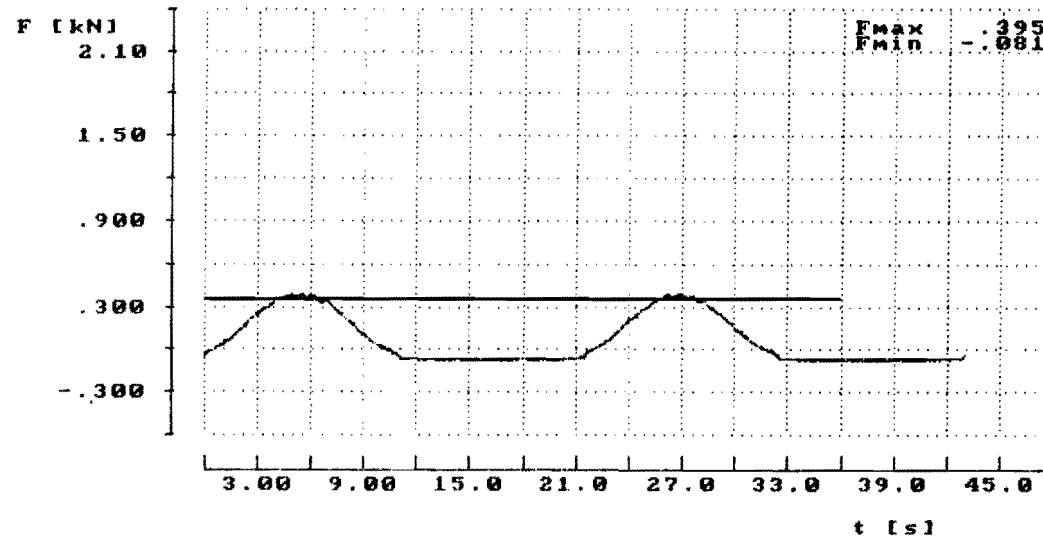
with lowest
variator ratio



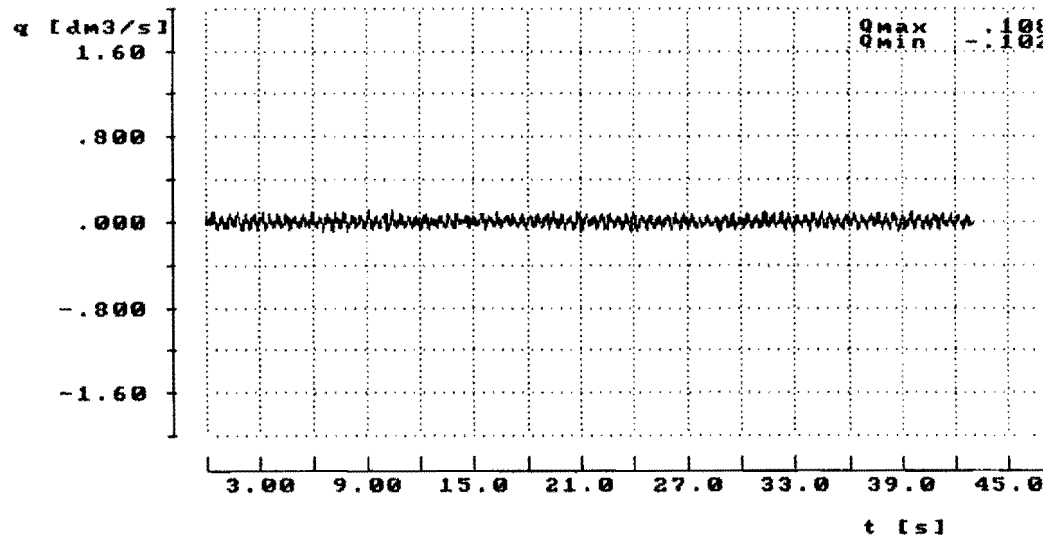
Pin [W]:
0.722
Pout[W]:
0

Evol :
0
Emech :
0

rotationspeed (rps): .035 number of rotations : 2.000
meanflow (dm3/s) : -.001 sample frequency (Hz): 34.662



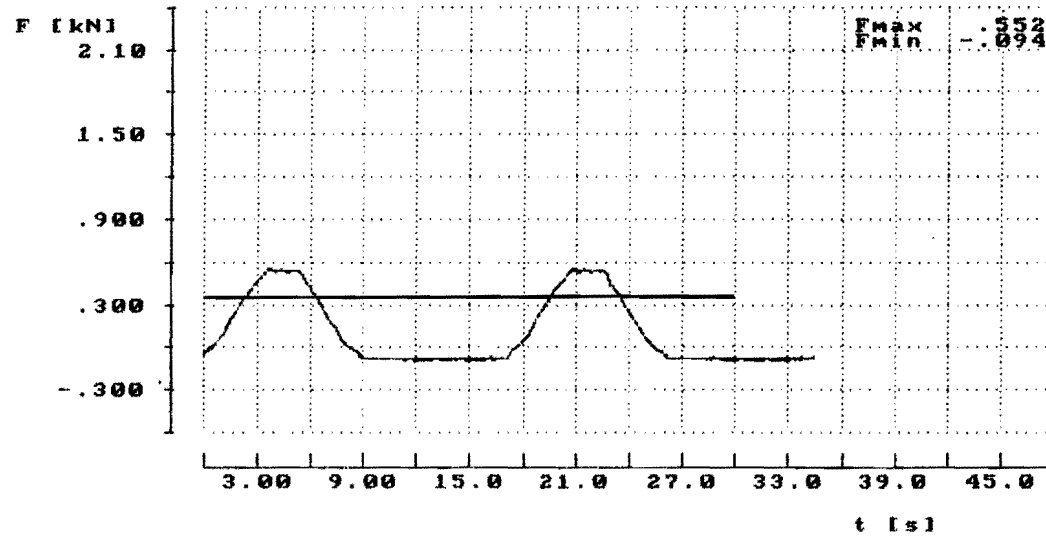
filename --> B:P0492A4._



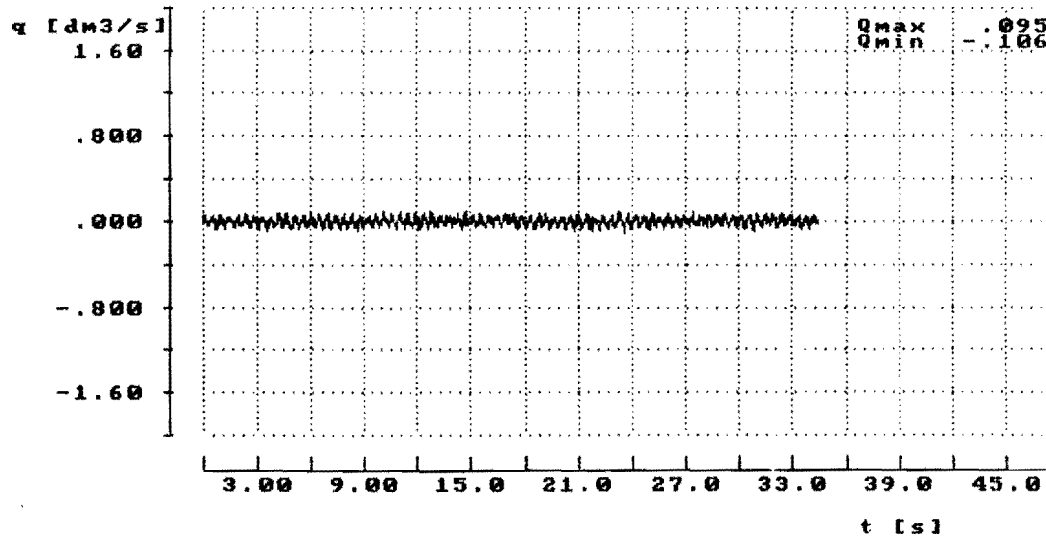
Pin [W]:
1.535
Pout[W]:
0

Evol :
0
Emech :
0

rotationspeed (rps): .047 number of rotations : 2.000
meanflow (dm3/s) : .000 sample frequency (Hz): 46.555



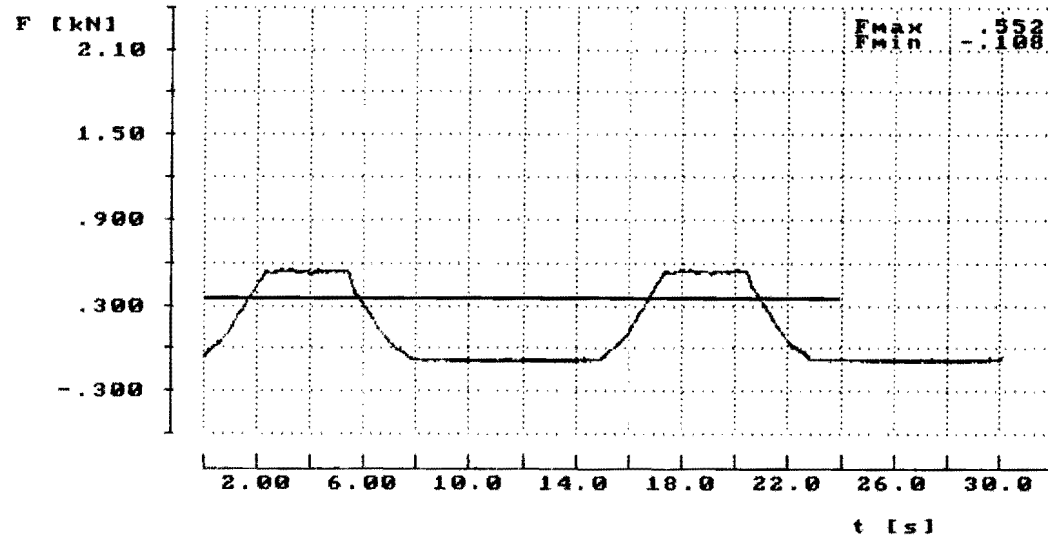
filename --> B:P0492A6._



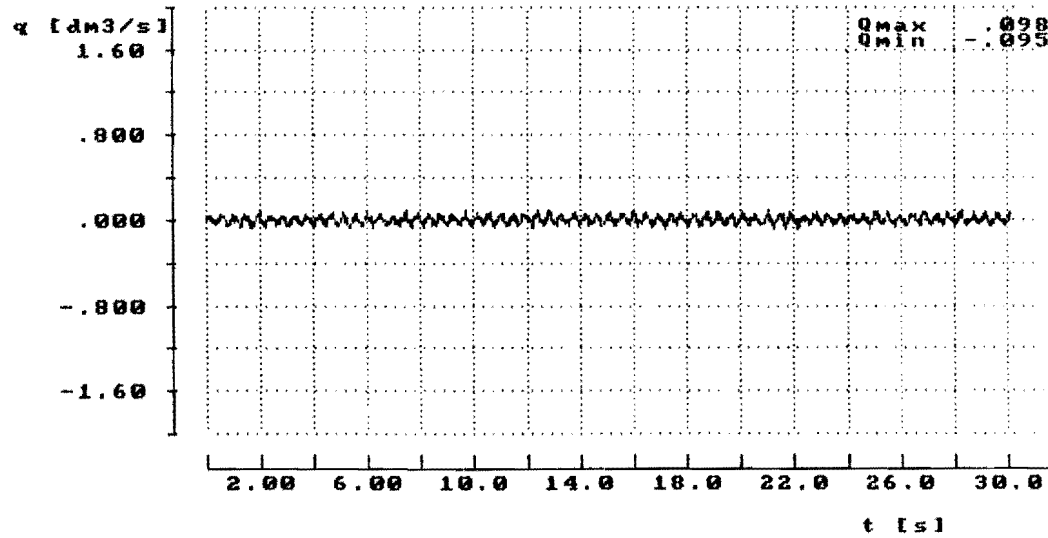
Pin [W]:
2.742
Pout[W]:
0

Evol :
0
Emech :
0

rotationspeed (rps): .058 number of rotations : 2.000
meanflow (dm3/s) : -.001 sample frequency (Hz): 58.140

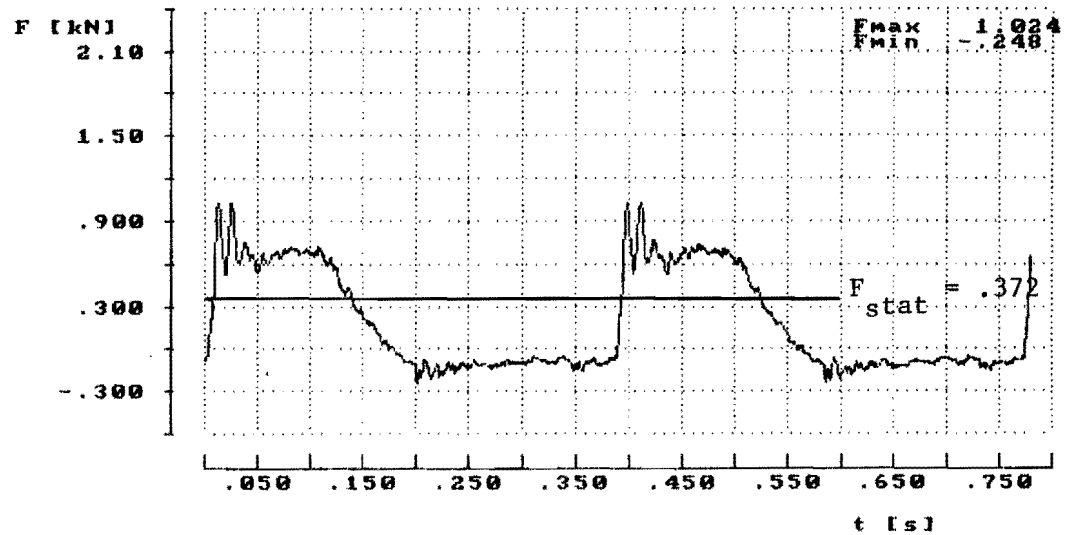


filename --> B:P0492A7._



Pin [W]:
3.442
Pout[W]:
0.101
Evol :
0.034
Emech :
0.030

rotationspeed (rps): .066 number of rotations : 2.000
meanflow (dm3/s) : .000 sample frequency (Hz): 66.401



filename --> B:P0493J1._

18 holes \emptyset 15

tube length = 0.5 m

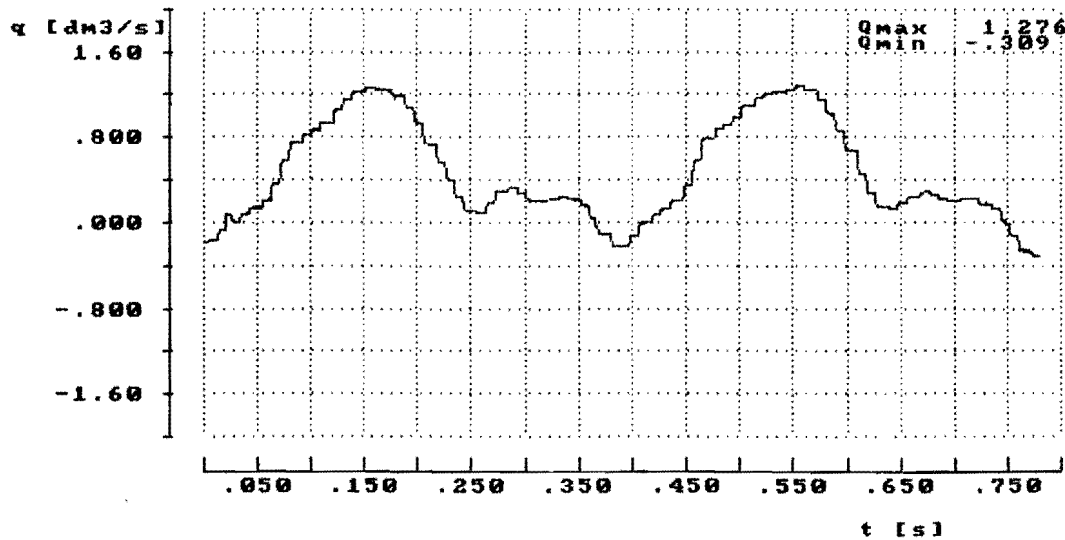
P_{pv} = 2 bar

H = 24.1 m

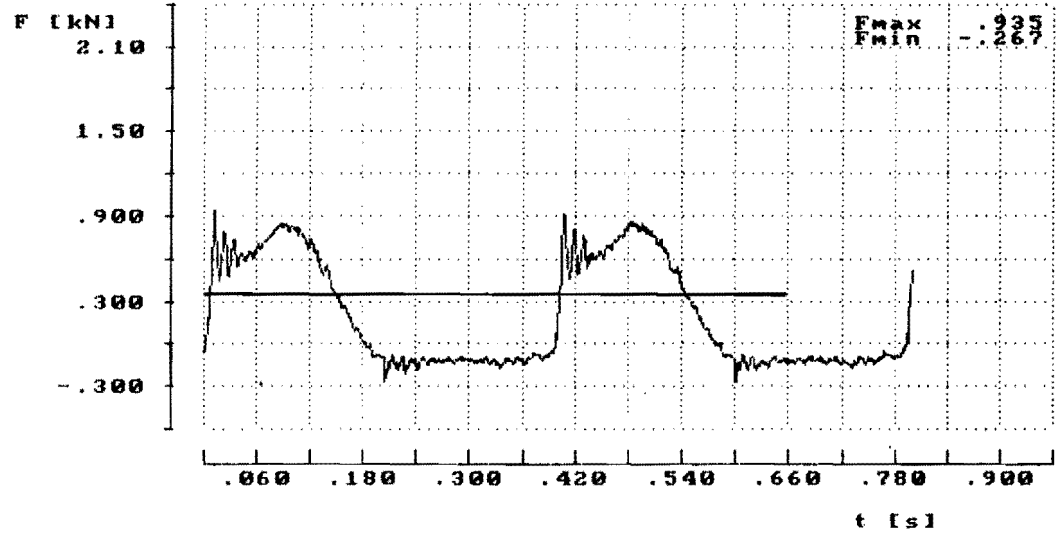
with highest variator
ratio

Pin [W]:
 168.253
Pout [W]:
 110.724

Evol :
 .969
Emech :
 0.658

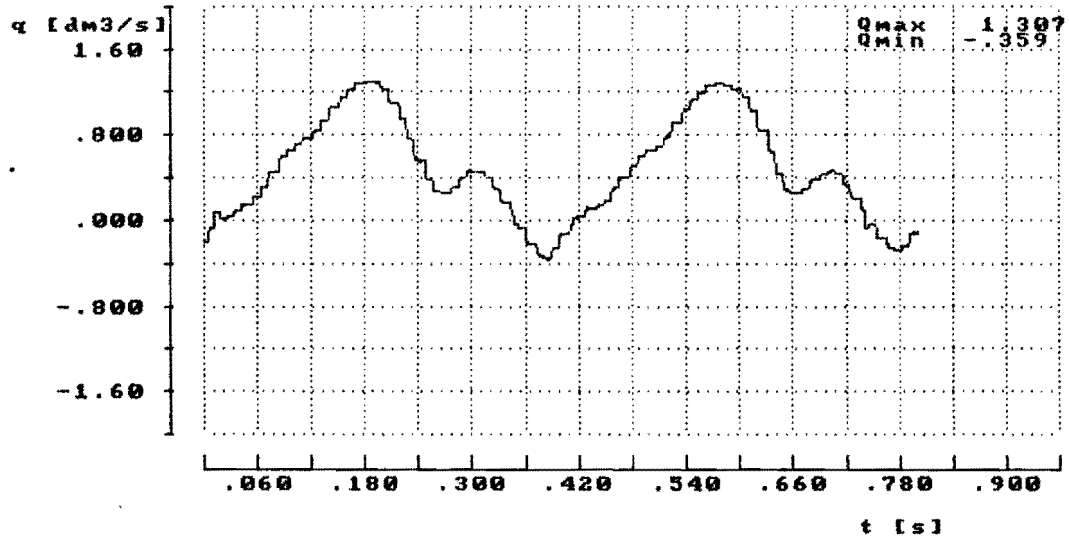


rotationspeed (rps): 2.564 **number of rotations : 2.000**
meanflow (dm3/s) : .468 **sample frequency (Hz): 2564.103**



filename --> B:P0494J1._

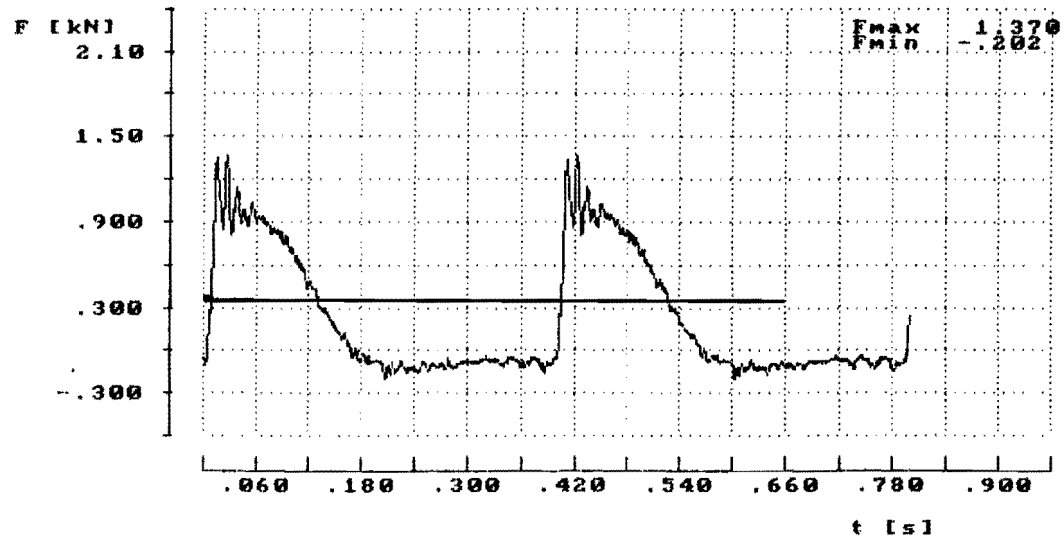
tube length = 1 m



Pin [W]:
183.196
Pout[W]:
112.024

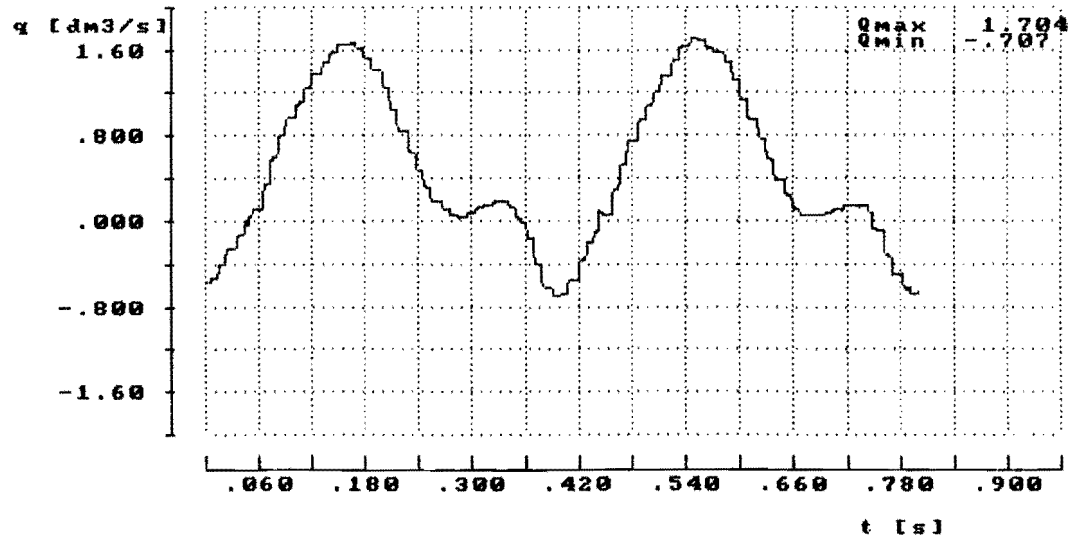
Evol :
1.005
Emech :
0.612

rotationspeed (rps): 2.500 number of rotations : 2.000
meanflow (dm3/s) : .474 sample frequency (Hz): 2500.000



filename --> B:P0498J1._

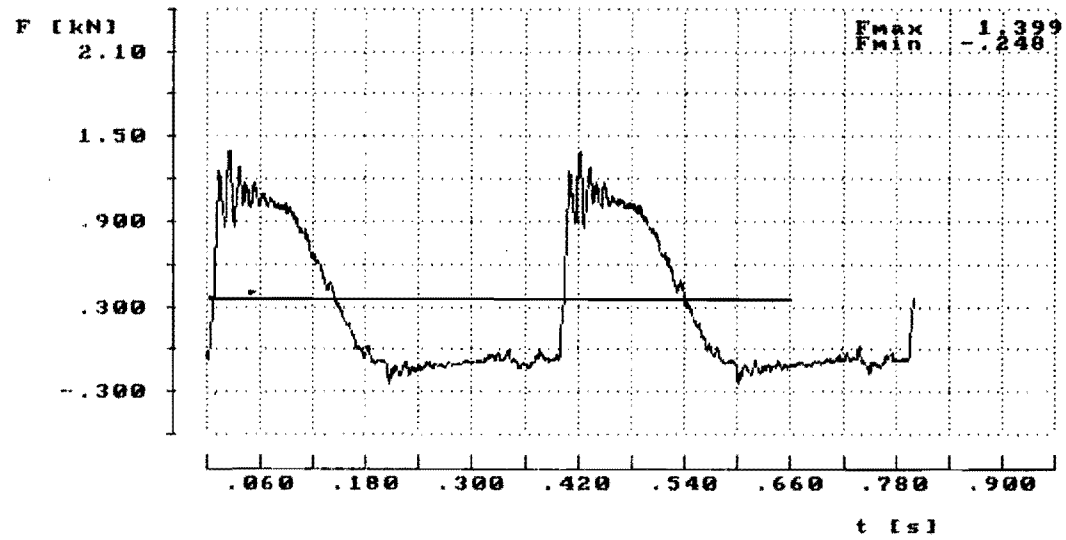
tube length = 1.5 m



Pin [W]:
 175.509
Pout [W]:
 111.335

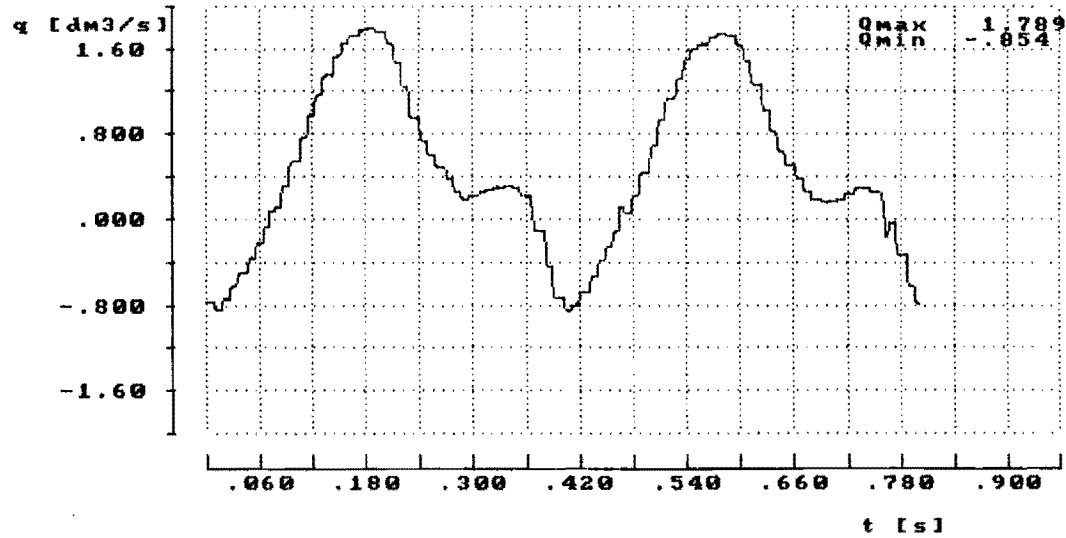
Evol :
 .999
Emech :
 0.634

rotationspeed (rps): 2.500 number of rotations : 2.000
 meanflow (dm3/s) : .471 sample frequency (Hz): 2500.000



filename --> B:P0495J1._

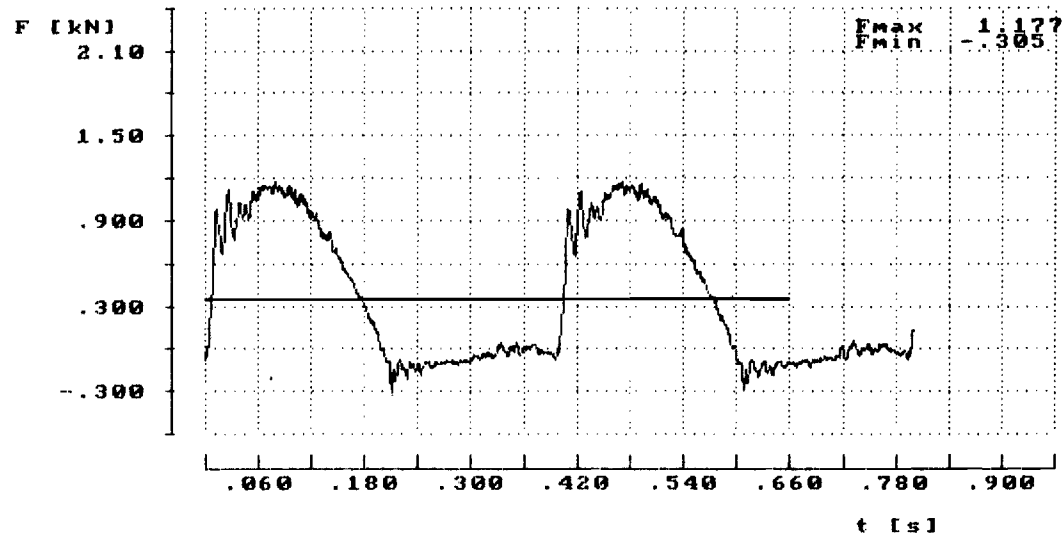
tube length = 2 m



Pin [W]:
211.335
Pout[W]:
112.319

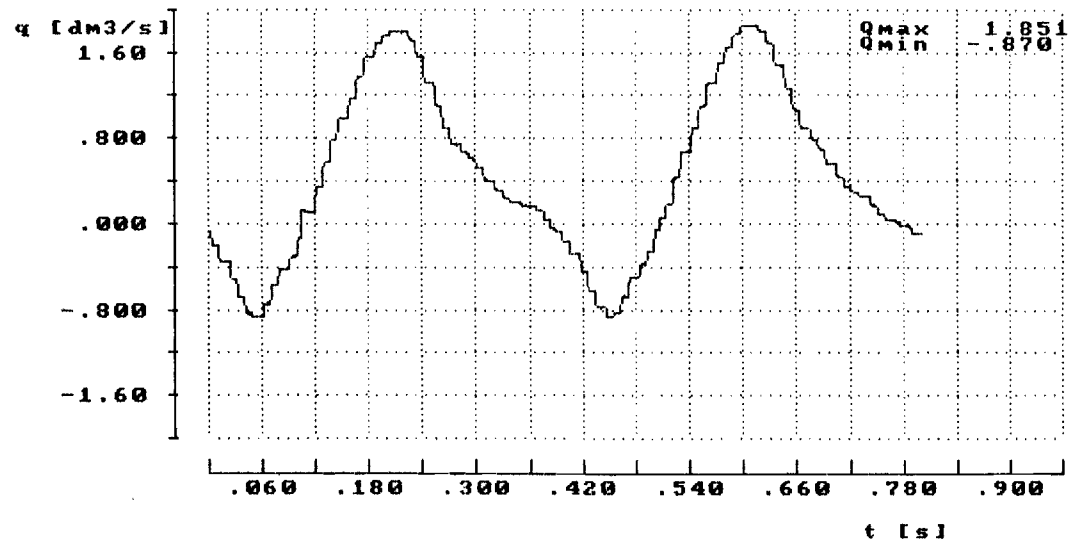
Evol :
1.008
Emech :
0.531

rotationspeed (rps): 2.500 number of rotations : 2.000
meanflow (dm³/s) : .475 sample frequency (Hz): 2500.000



filename --> B:P0496J1._

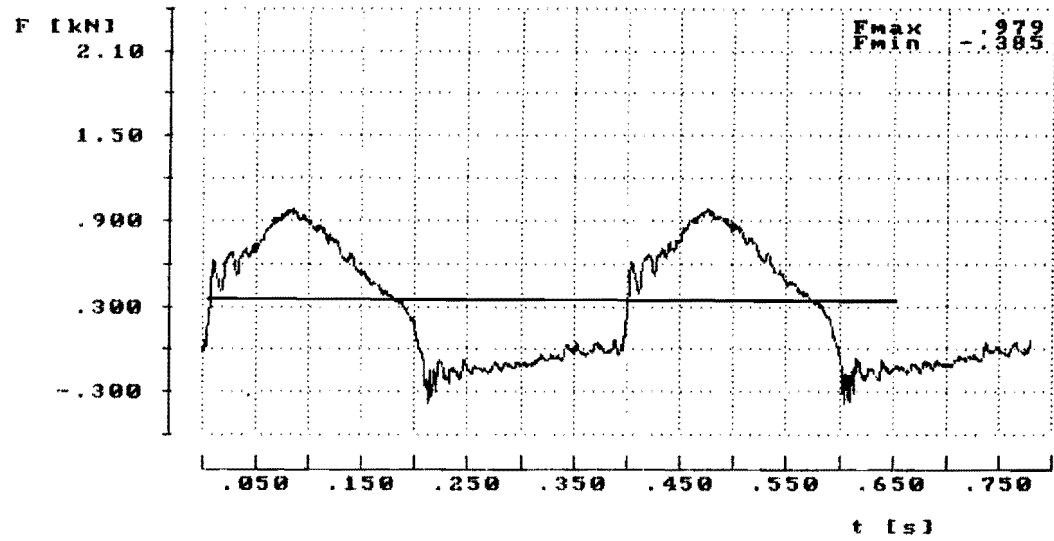
tube length = 3 m



Pin [W]:
 242.792
Pout[W]:
 108.071

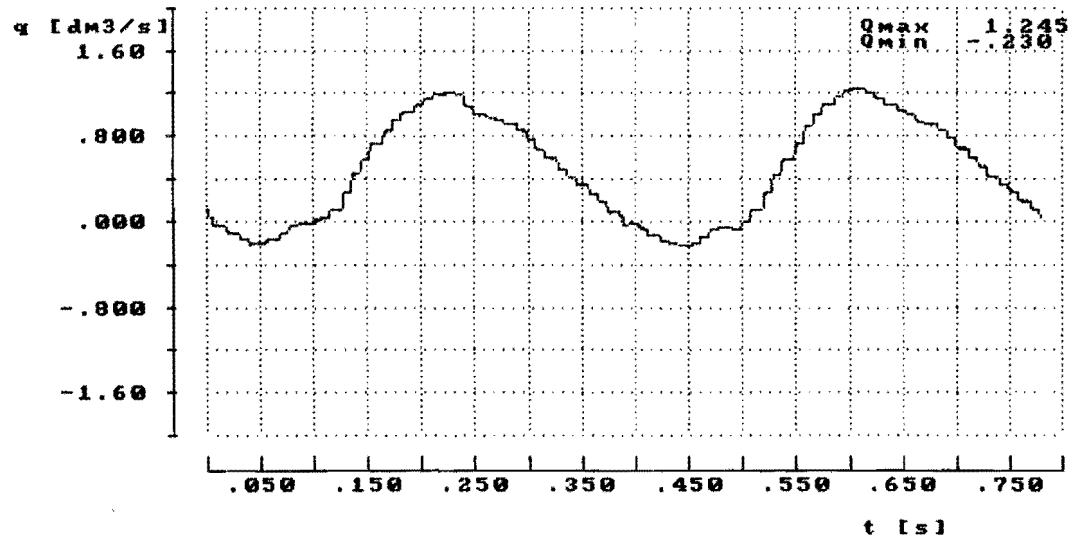
Evol :
 .970
Emech :
 0.445

rotationspeed (rps): 2.500 **number of rotations : 2.000**
meanflow (dm3/s) : .457 **sample frequency (Hz): 2500.000**



filename --> B:P0497J1_

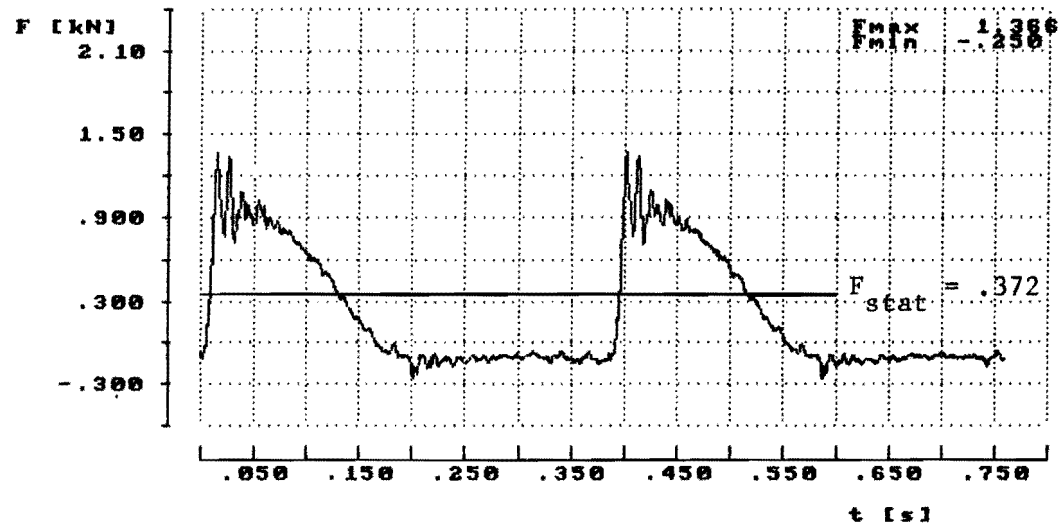
tube length = 4 m



Pin [W]:
211.607
Pout [W]:
112.507

Evol :
.988
Emech :
0.532

rotationspeed (rps): 2.564 number of rotations : 2.000
meanflow (dm3/s) : .478 sample frequency (Hz): 2564.103

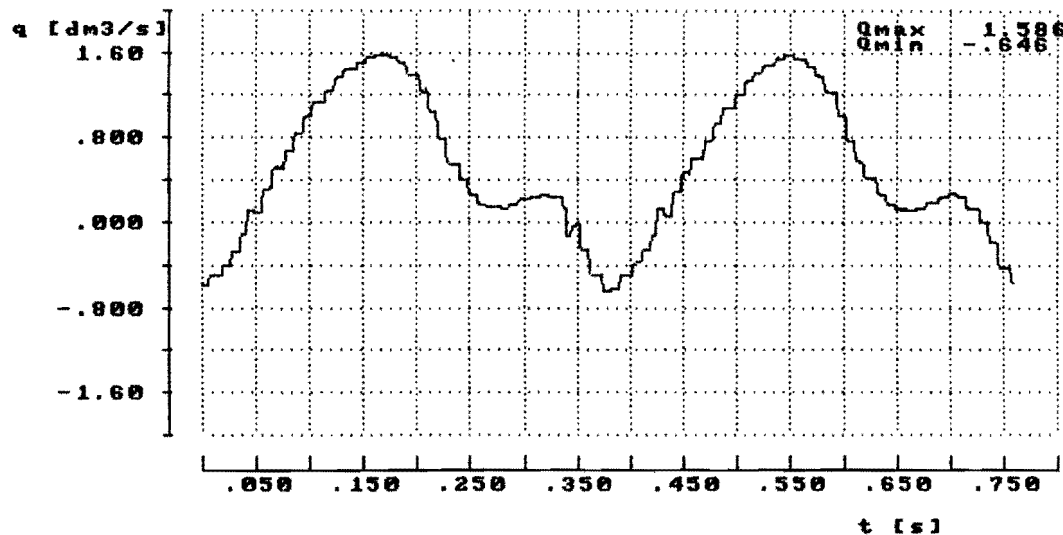


filename --> B:P0499J.

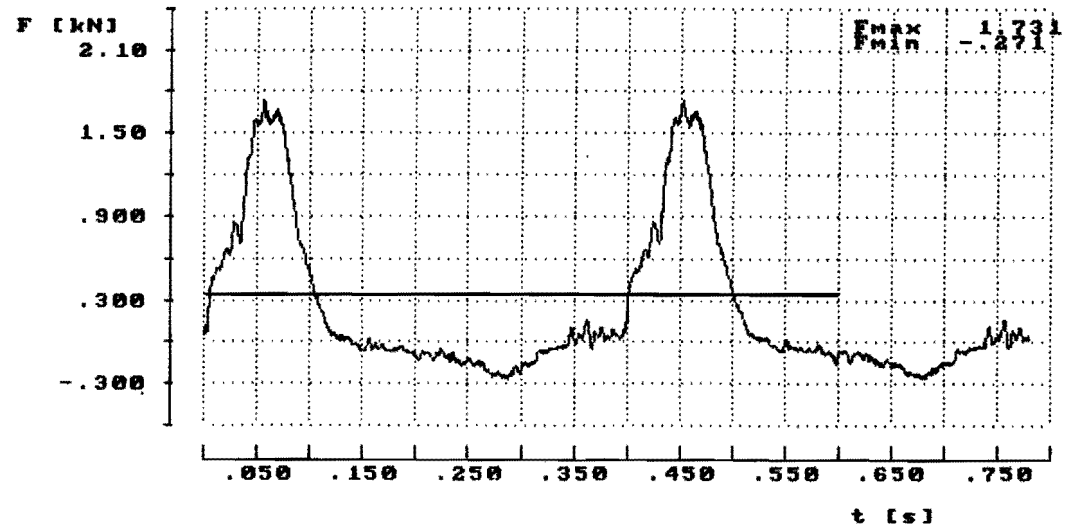
36 holes \varnothing 15
 tube length = 1.5 m
 $P_{pv} = 2$ bar
 $H = 24.1$ m

P_{in} [W]:
 186.253
P_{out} [W]:
 121.381

E_{vol} :
 1.035
E_{mech} :
 0.652



rotationspeed (rps): 2.632 **number of rotations :** 2.000
meanflow (dm³/s) : .513 **sample frequency (Hz):** 2631.579

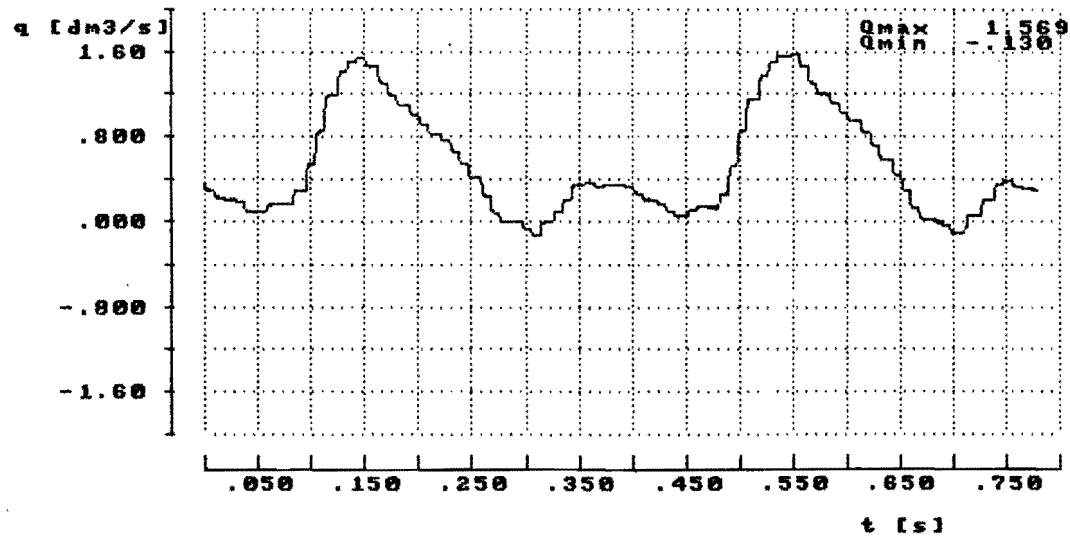


filename --> B:P04914J._

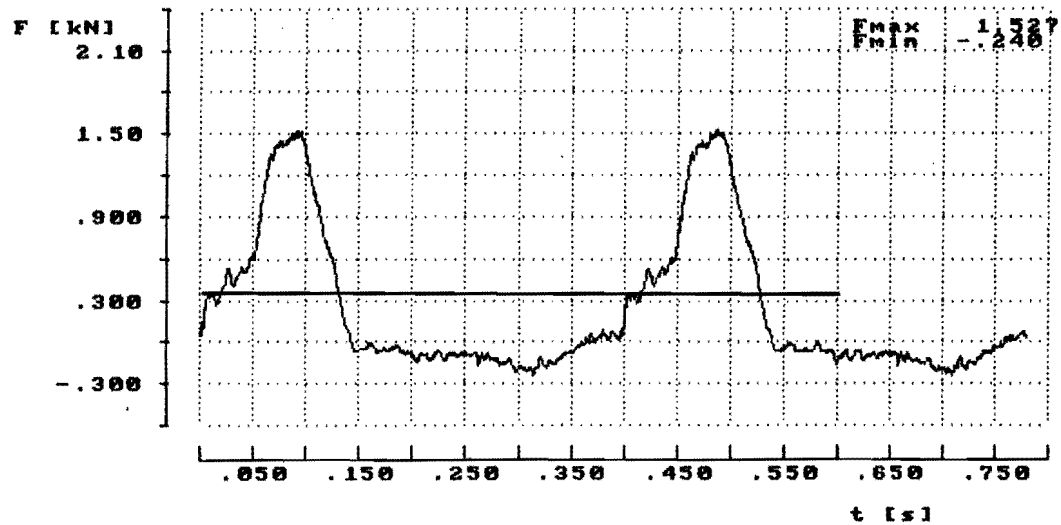
4 holes \varnothing 20
 tube length = 0.25 m
 P_{pv} = 2 bar
 H = 24.1 m

Pin [W]:
 189.562
Pout[W]:
 125.156

Evol :
 1.095
Erech :
 0.660

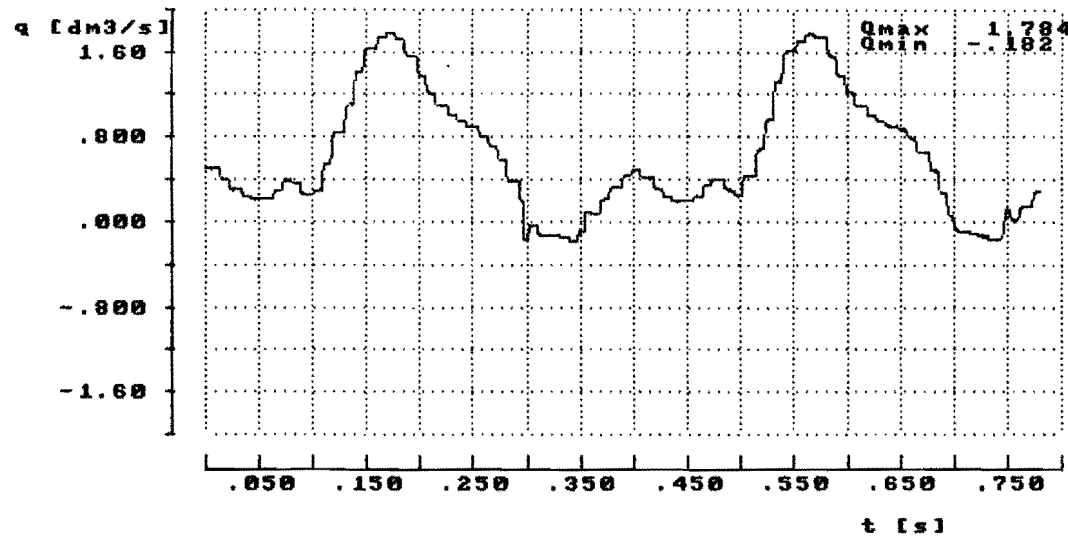


rotationspeed (rps): 2.564 **number of rotations :** 2.000
meanflow (dm3/s) : .529 **sample frequency (Hz):** 2564.103



filename --> B:P04915J._

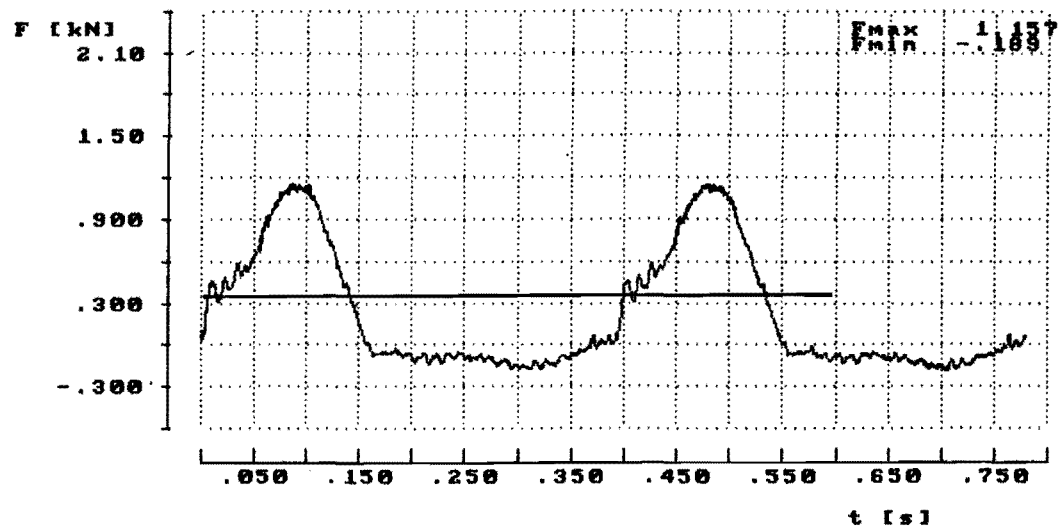
tube length = 0,5 m



Pin [W]:
 220.016
Pout[W]:
 145.717

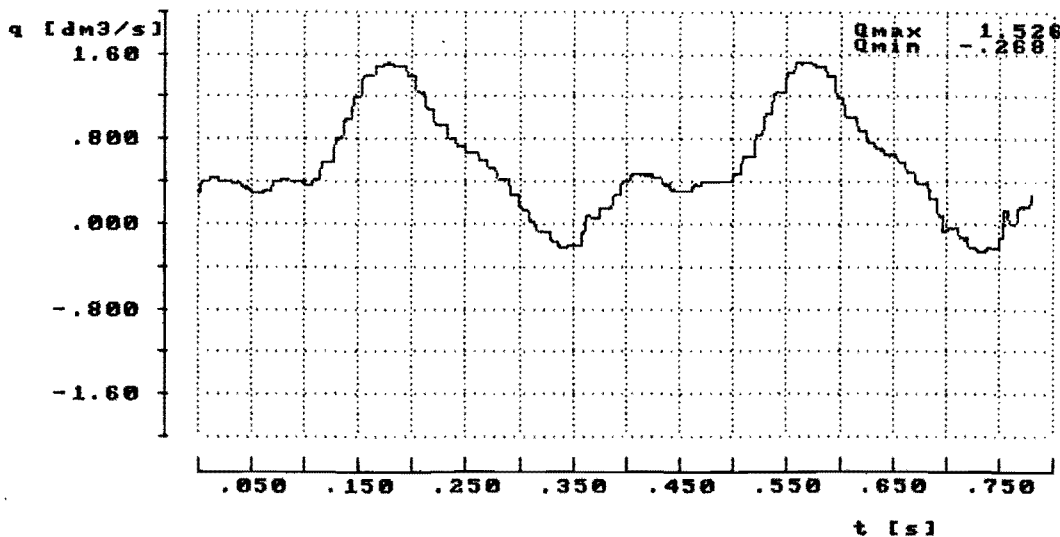
Evol :
 1.275
Emech :
 0.656

rotationspeed (rps): 2.564 number of rotations : 2.000
 meanflow (dm3/s) : .616 sample frequency (Hz): 2564.103



filename --> B:P04916J._

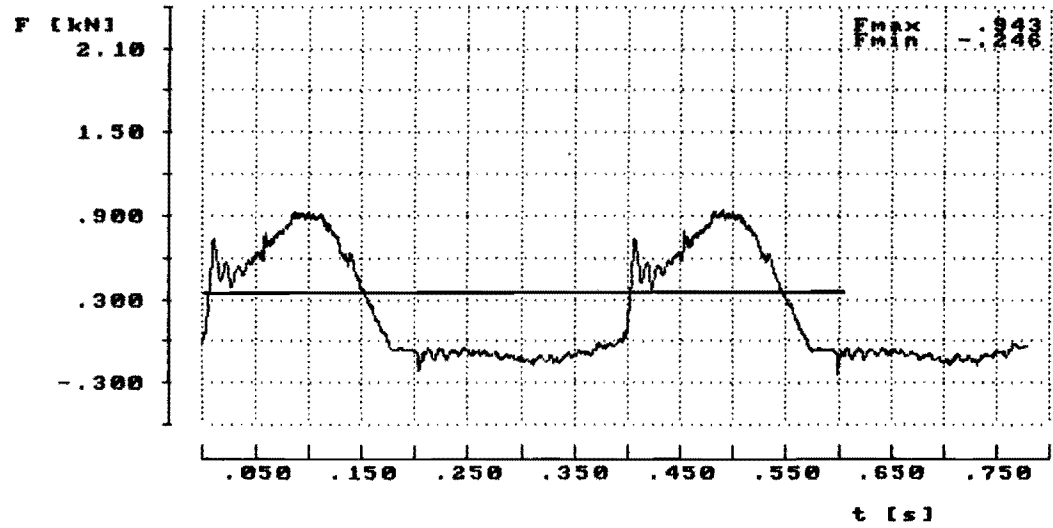
tube length = 0.75 m



Pin [W]:
204.175
Pout [W]:
129.267

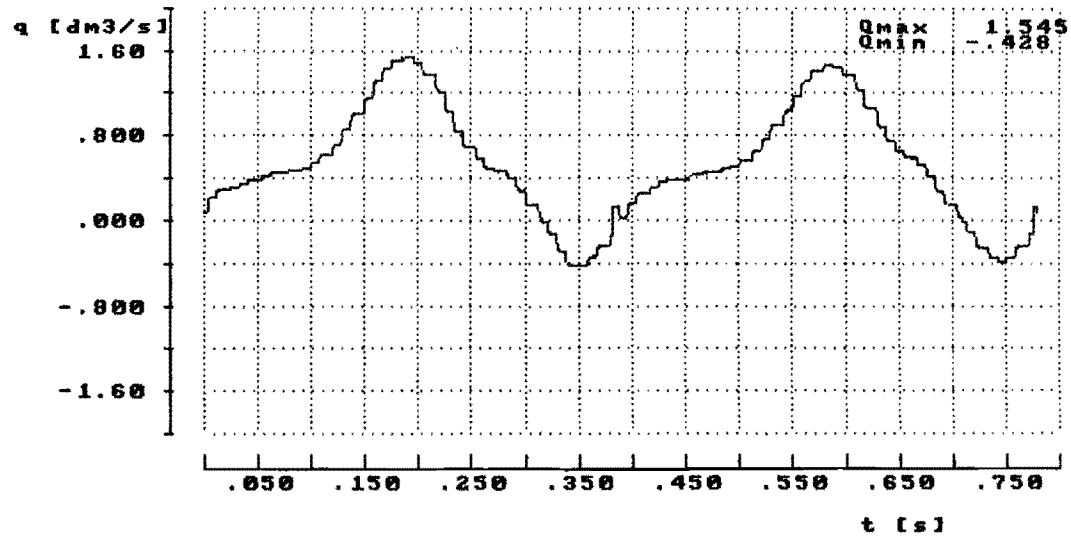
Evol :
1.138
Emech :
0.633

rotationspeed (rps): 2.564 number of rotations : 2.000
meanflow (dm3/s) : .549 sample frequency (Hz): 2564.103



filename --> B:P04917J...

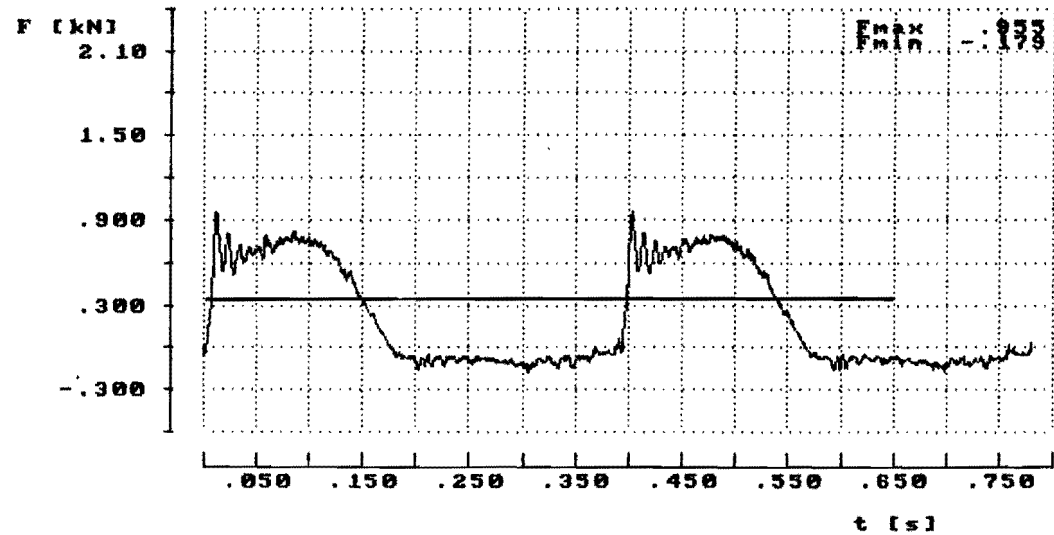
tube length = 1 m



Pin [W]:
191.018
Pout[W]:
124.382

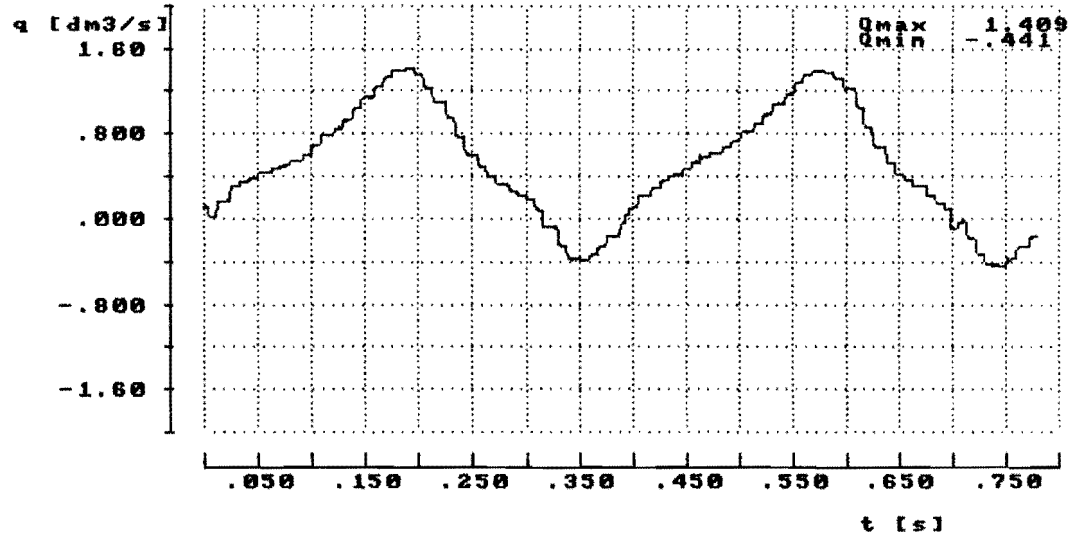
Evol :
1.093
Emech :
0.650

rotationspeed (rps): 2.564 number of rotations : 2.000
meanflow (dm3/s) : .528 sample frequency (Hz): 2564.103



filename --> B:P04918J._

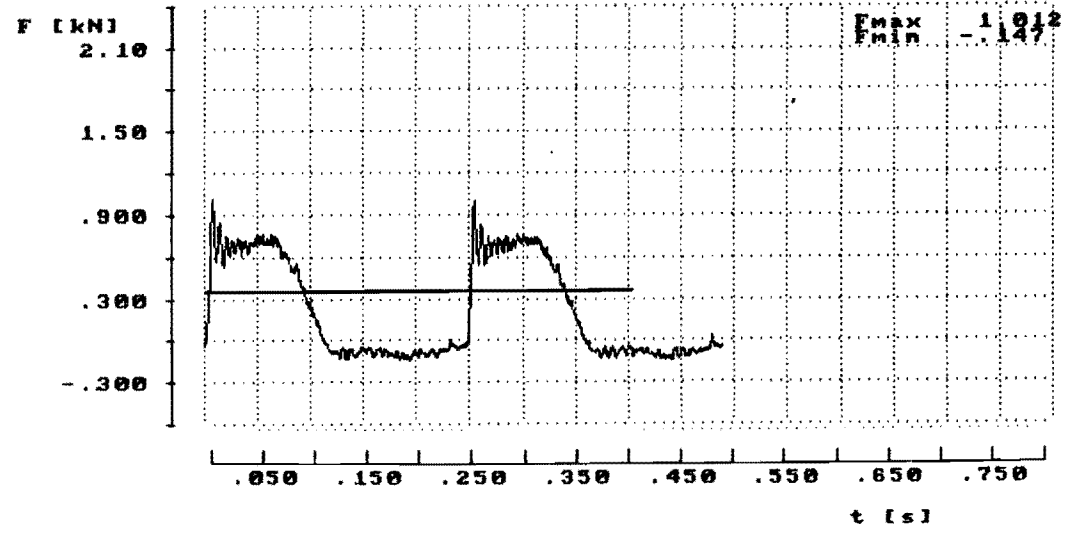
tube length = 1.15 m



Pin [W]:
179.06
Pout[W]:
118.220

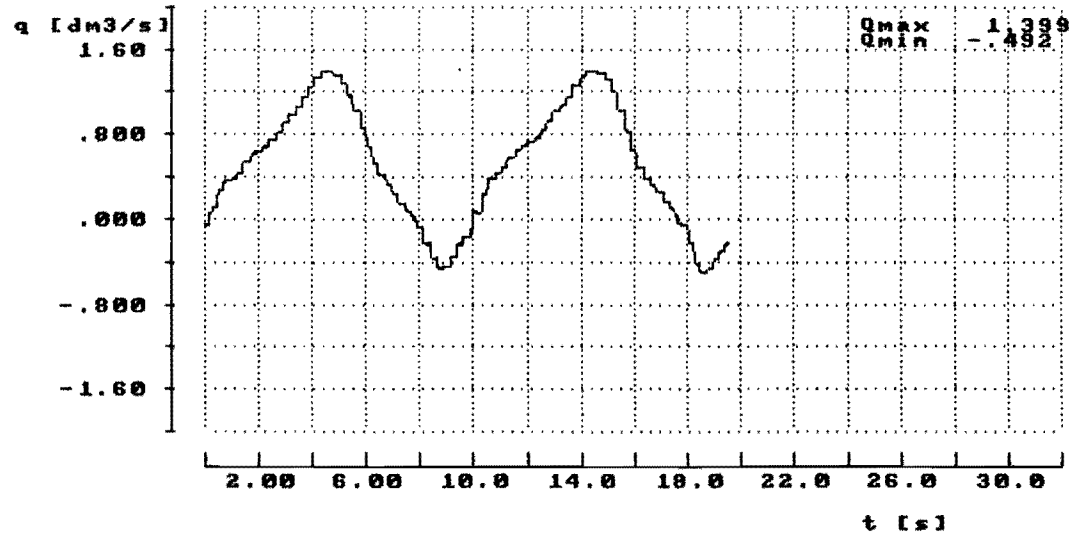
Evol :
1.038
Emech :
0.660

rotationspeed (rps): 2.564 number of rotations : 2.000
meanflow (dm3/s) : .502 sample frequency (Hz): 2564.103



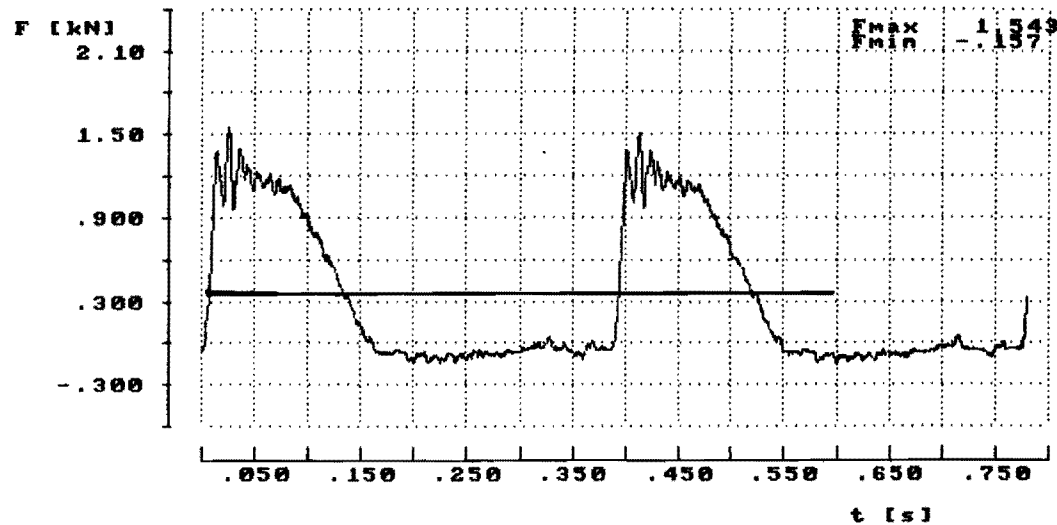
filename --> B:P04919J_

tube length = 1.25 m



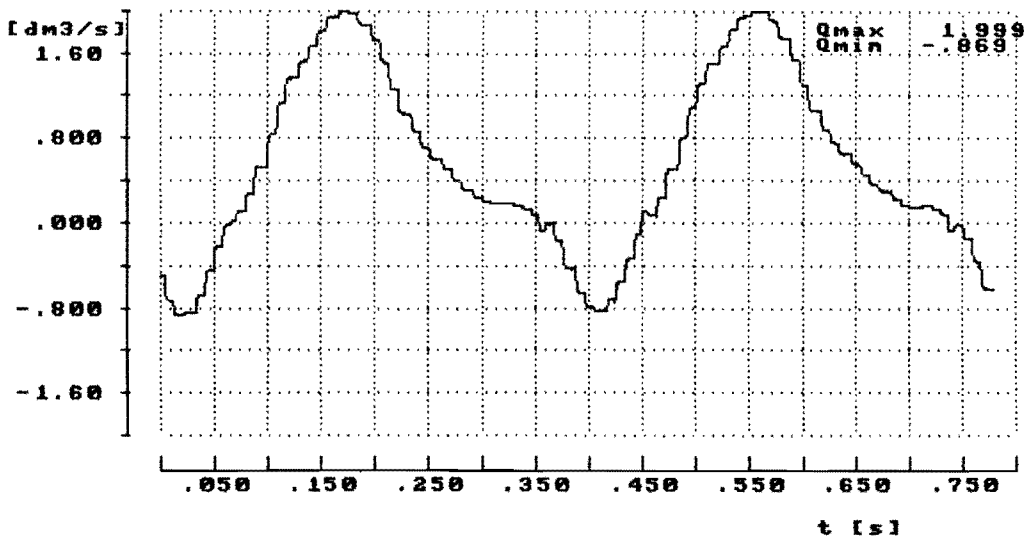
Pin [W]:
173.878
Pout[W]:
1.071
Evol :
26.815
Erech :
0.702

rotationspeed (rps): .102 number of rotations : 2.000
meanflow (dm3/s) : .518 sample frequency (Hz): 102.459



filename --> B:P04920J._

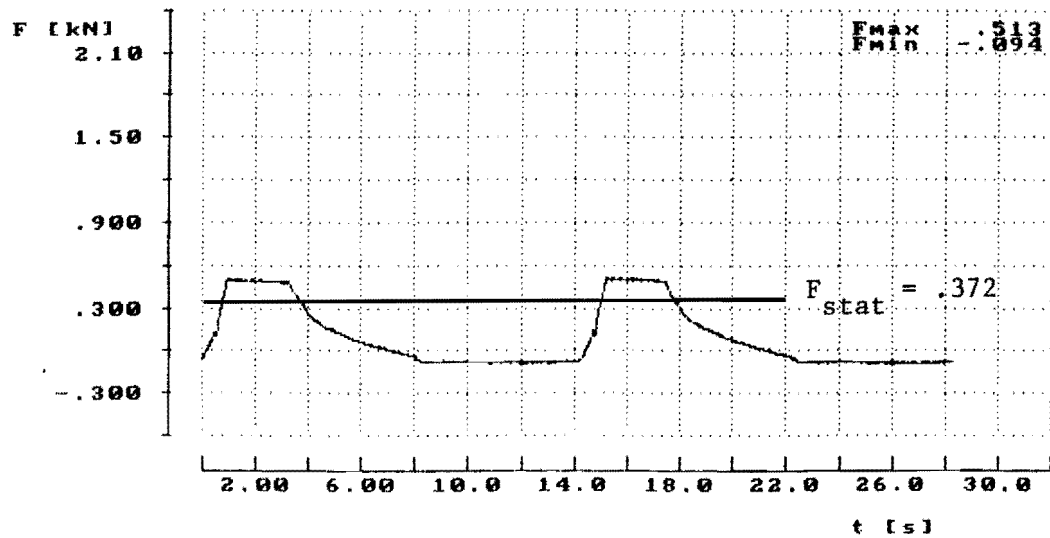
tube length = 1.45 m



Pin [W]:
212.5
Pout[W]:
129.447

Evol :
1.132
Emech :
0.609

rotationspeed (rps): 2.564 number of rotations : 2.000
meanflow (dm3/s) : .548 sample frequency (Hz): 2564.103

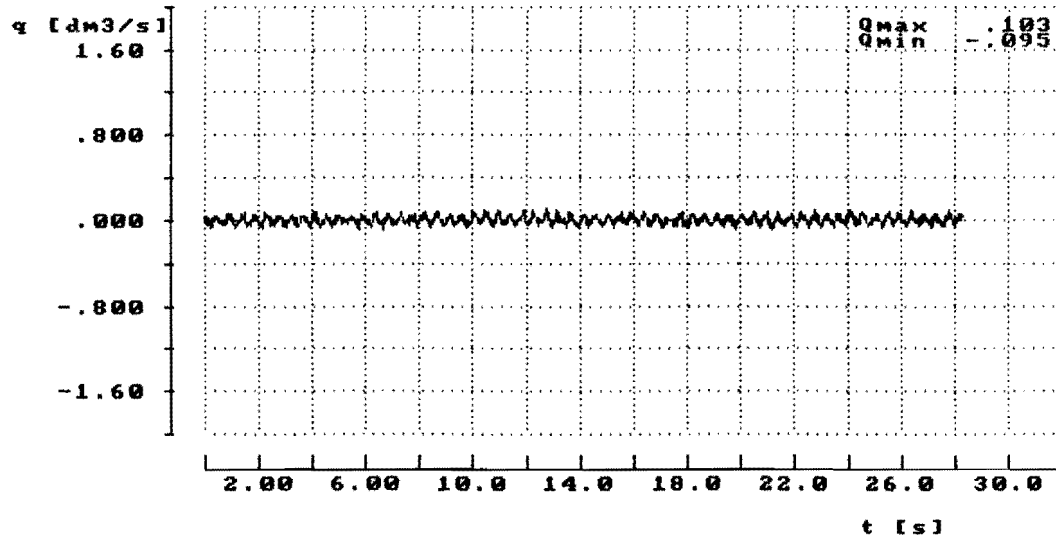


filename --> B:P04921A...

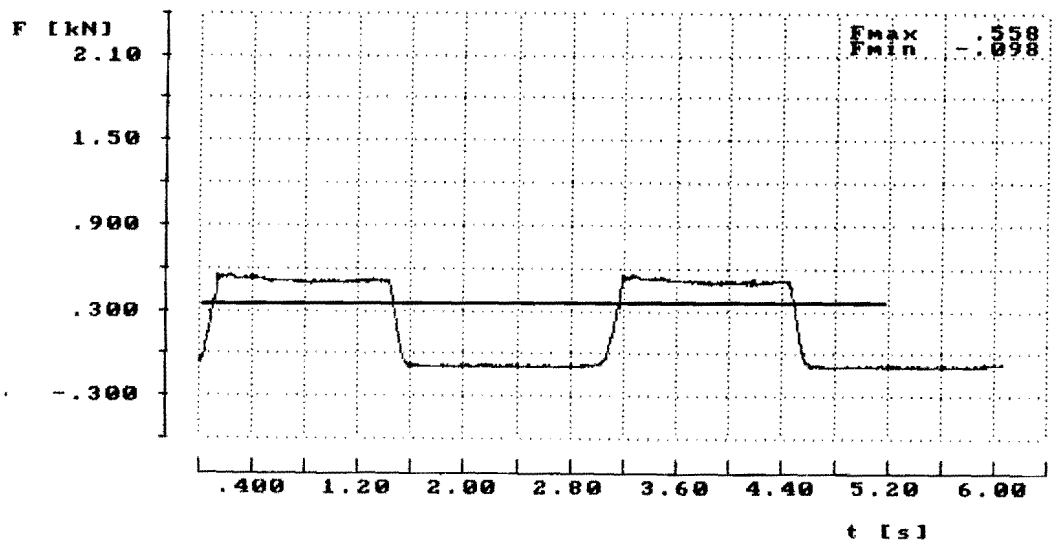
4 holes ϕ 20
 tube length = 1 m
 $P_{pv} = 2$ bar
 $H = 24.1$ m

Pin [W]:
 3.093
 Pout [W]:
 0

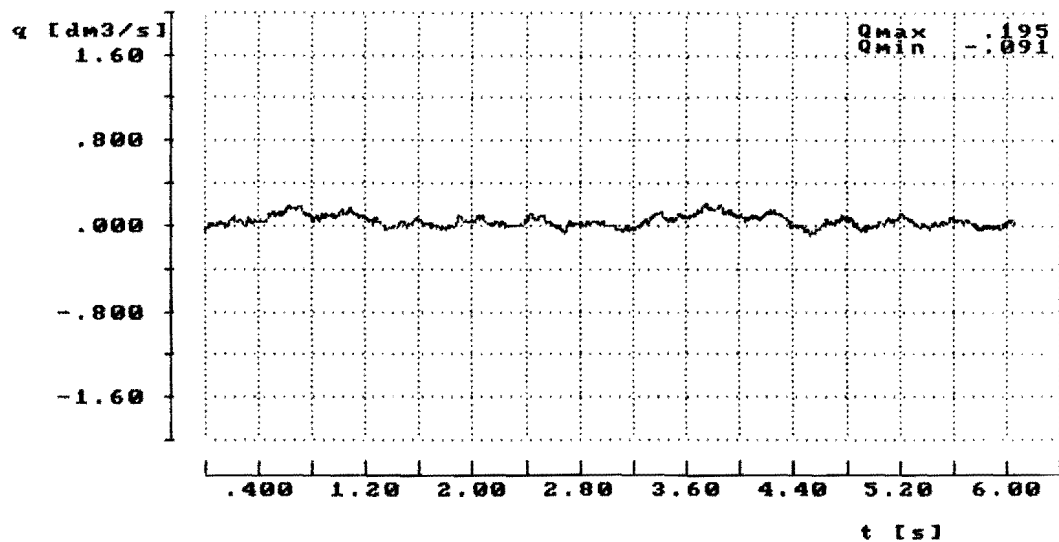
Evol :
 0
 Emech :
 0



rotationspeed (rps): .071 number of rotations : 2.000
 meanflow (dm3/s) : -.001 sample frequency (Hz): 70.721



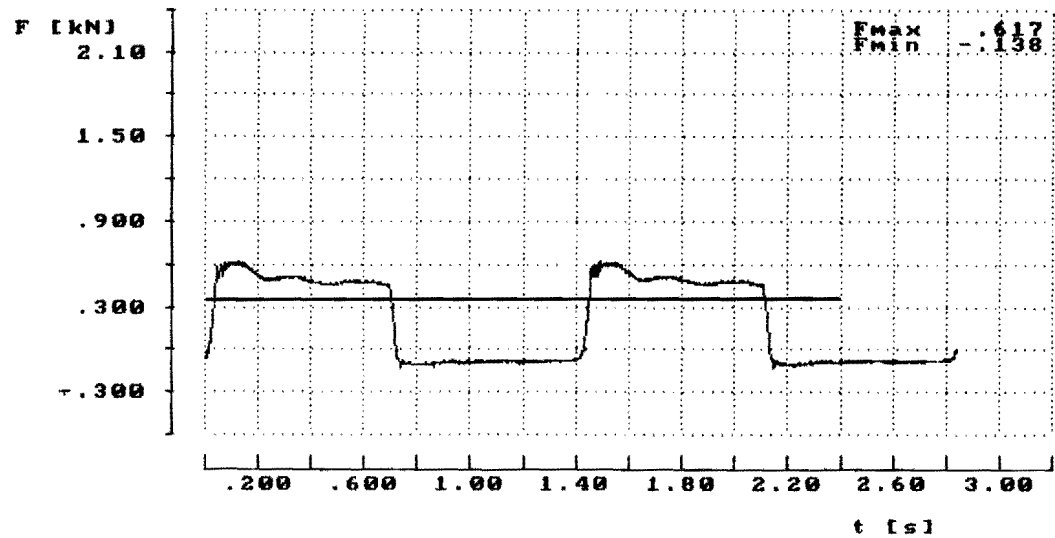
filename --> B:P04921B._



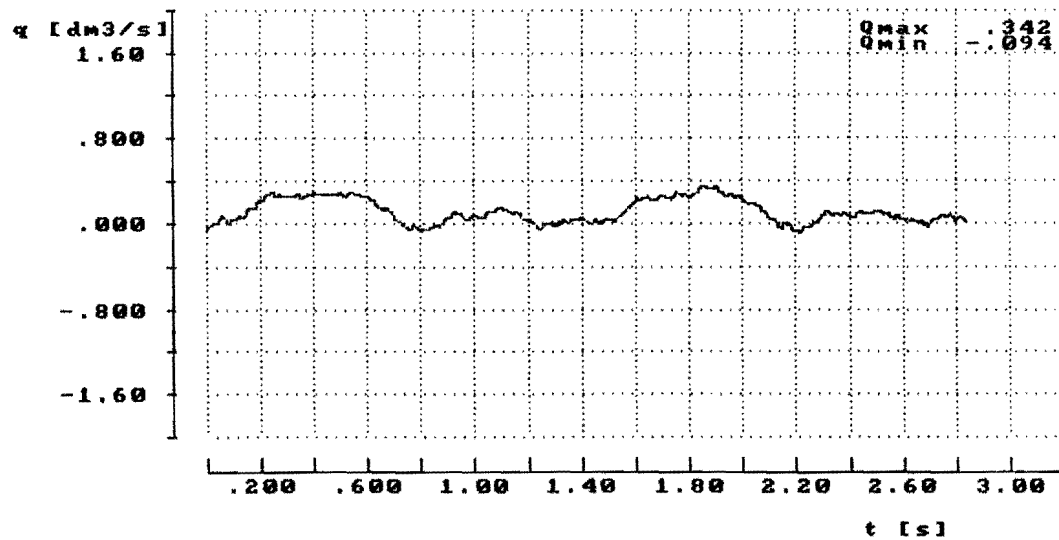
Pin [W]:
19.558
Pout[W]:
9.849

Evol :
.672
Emech :
0.504

rotationspeed (rps): .330 number of rotations : 2.000
meanflow (dm3/s) : .042 sample frequency (Hz): 330.033



filename --> B:P04921D._



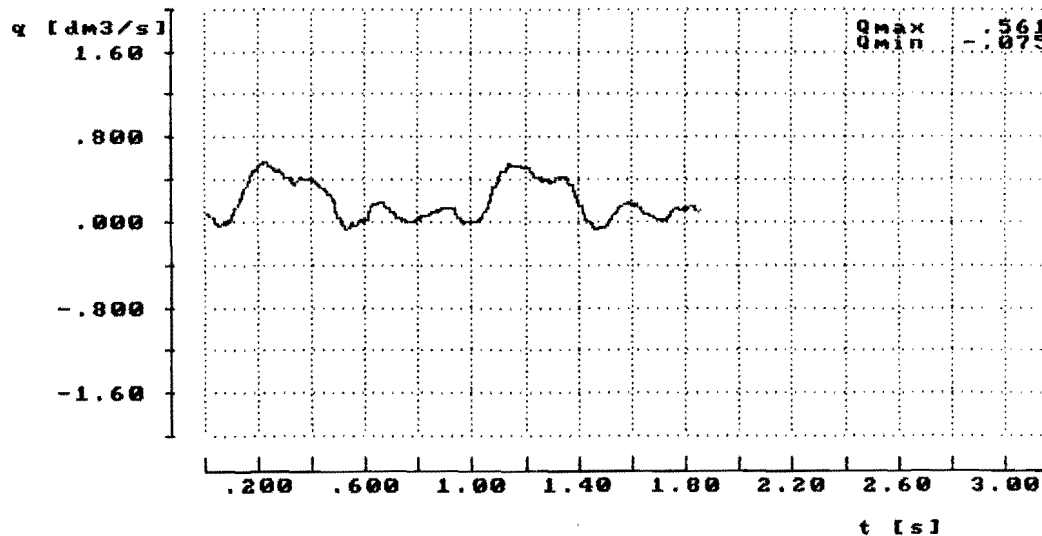
Pin [W]:
41.35
Pout[W]:
26.377

Evol :
.844
Emech :
0.637

rotationspeed (rps): .704 number of rotations : 2.000
meanflow (dm3/s) : .112 sample frequency (Hz): 704.225



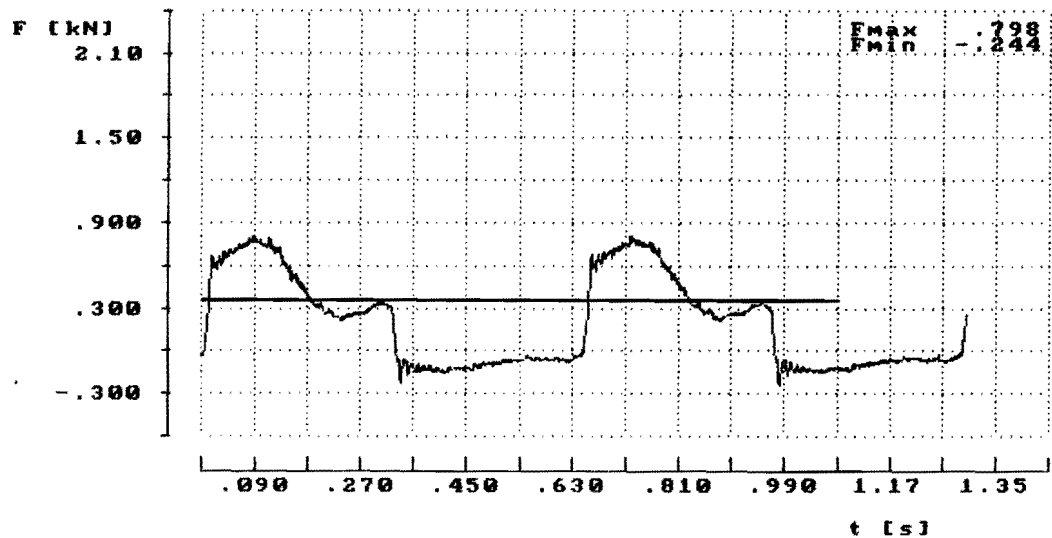
filename --> B:P04921F._



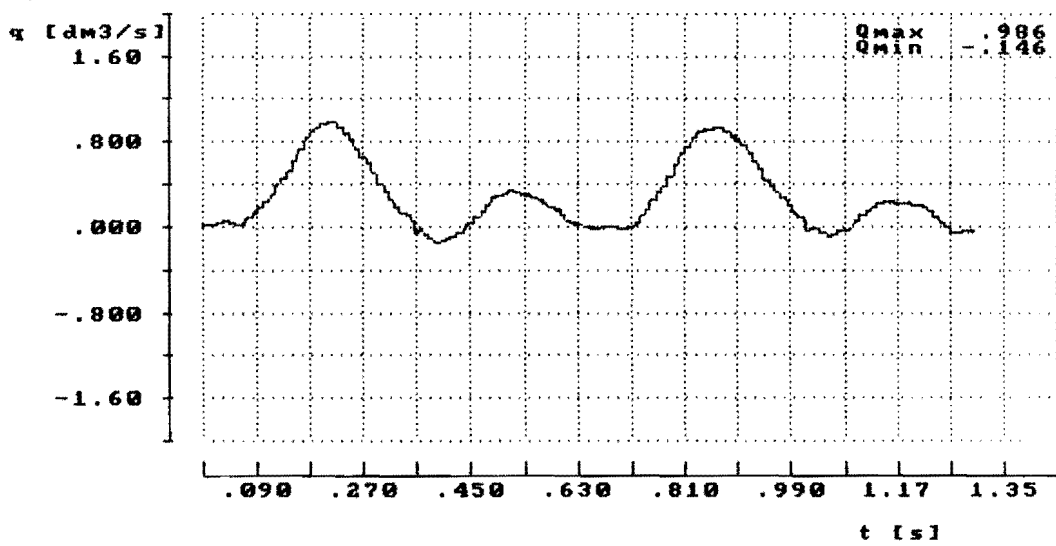
Pin [W]:
63.147
Pout[W]:
44.450

Evol :
.931
Emech :
0.704

rotationspeed (rps): 1.075 number of rotations : 2.000
meanflow (dm3/s) : .189 sample frequency (Hz): 1075.269



filename --> B:P04921H._



Pin [W]:
91.041

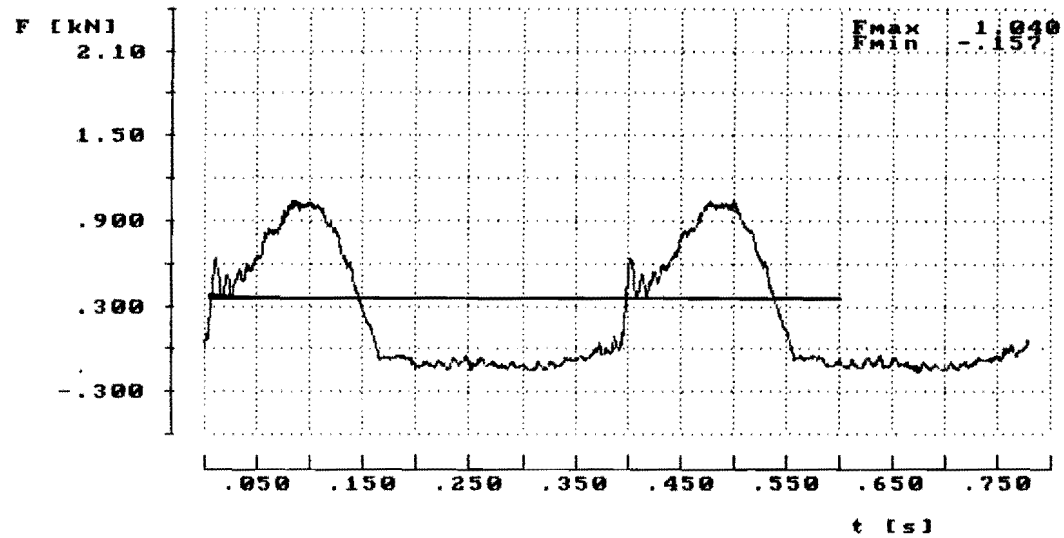
Pout[W]:
64.889

Evol :
.950

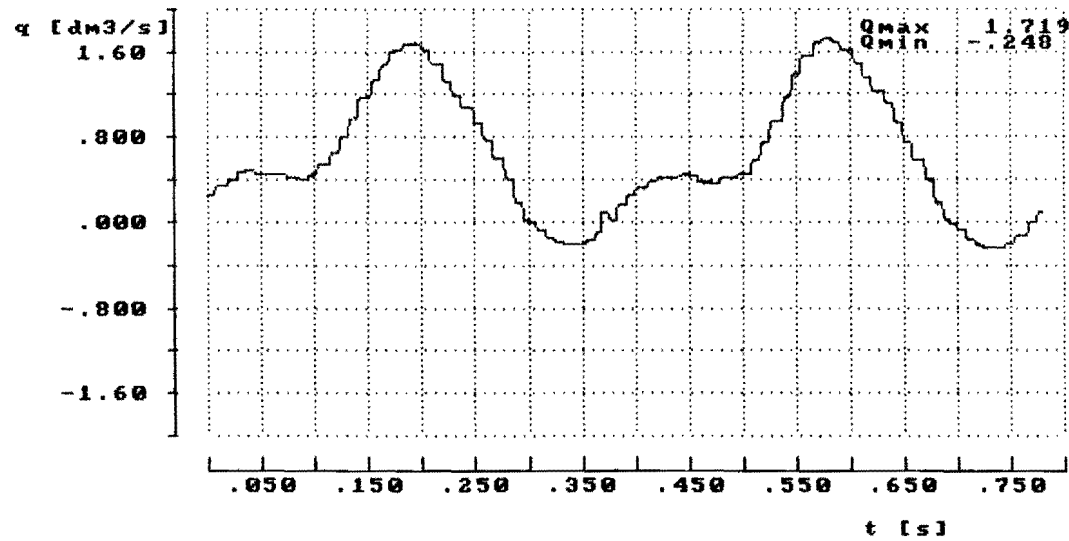
Emech :
0.713

rotationspeed (rps): 1.538 number of rotations : 2.000

meanflow (dm3/s) : .276 sample frequency (Hz): 1538.462



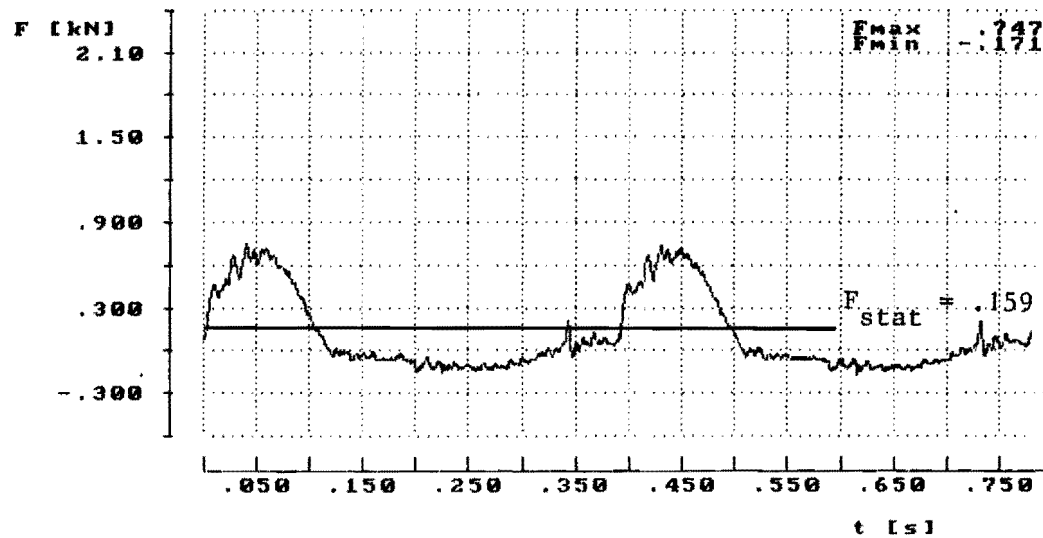
filename --> B:P04921J._



Pin [W]:
 201.248
Pout[W]:
 144.036

Evol :
 1.265
Emech :
 0.716

rotationspeed (rps): 2.564 **number of rotations :** 2.000
meanflow (dm3/s) : .612 **sample frequency (Hz):** 2564.103

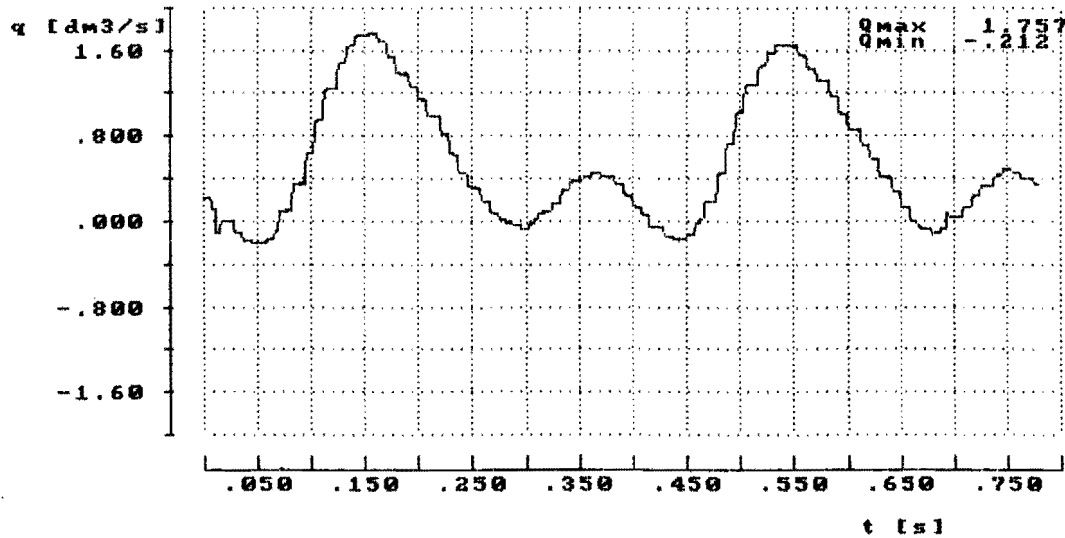


filename --> B:P04922J._

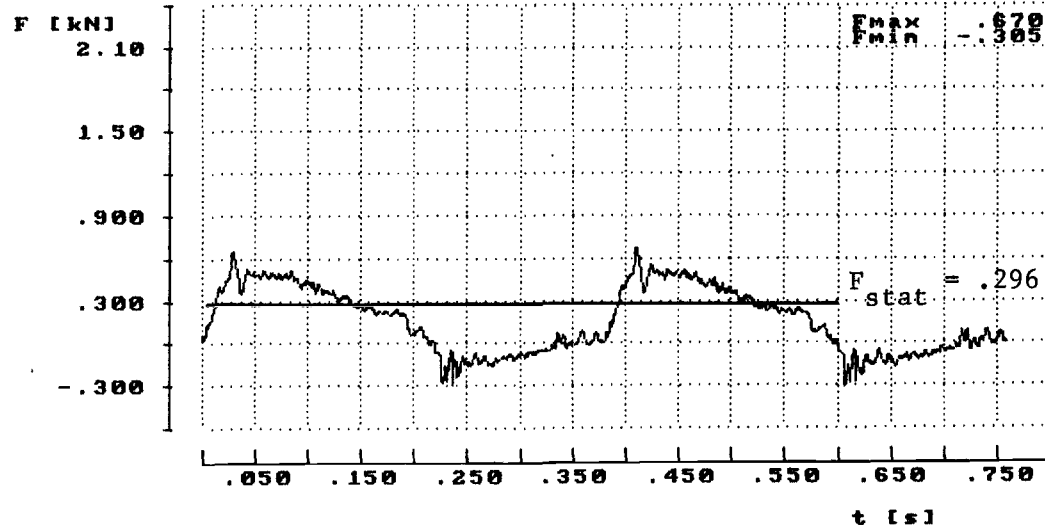
4 holes \emptyset 20
 tube length = 1 m
 H = 10.3 m

Pin [W]:
 90.065
Pout [W]:
 47.775

Evol :
 1.119
E_{mech} :
 0.530



rotationspeed (rps): 2.564 **number of rotations : 2.000**
meanflow (dm3/s) : .541 **sample frequency (Hz): 2564.103**

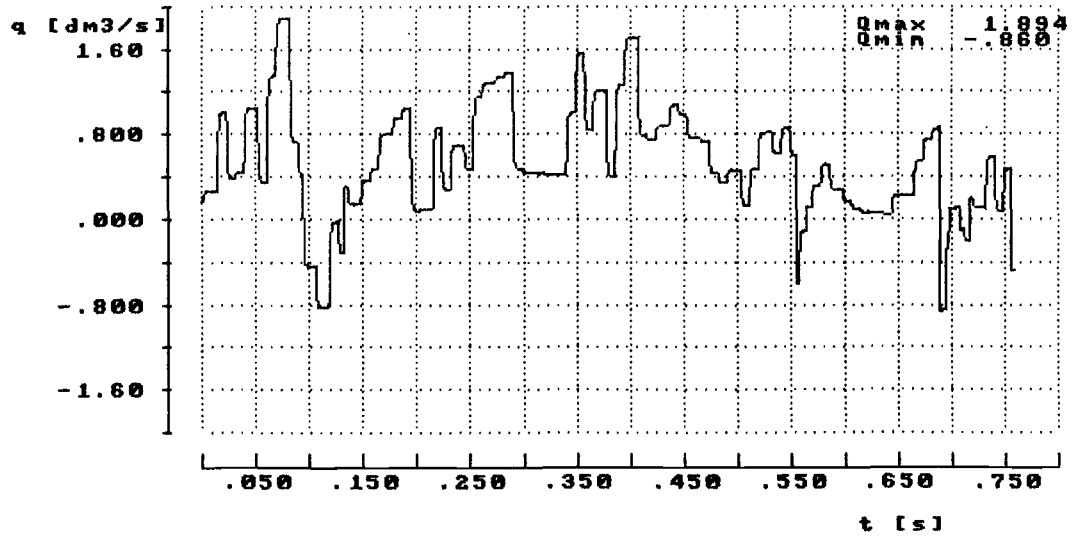


filename --> B:P04923J1...

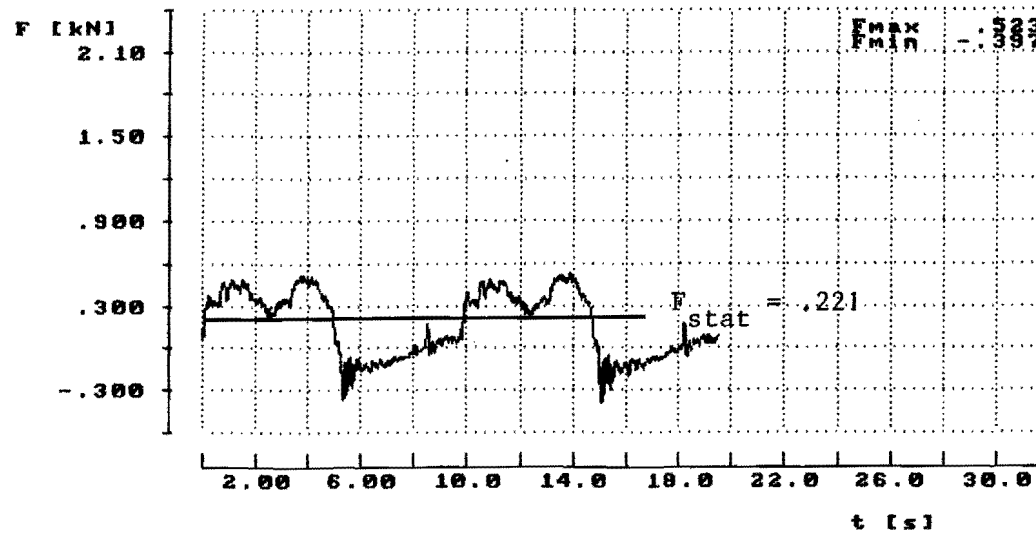
4 holes ϕ 20
 tube length = 1 m
 P_{pv} = 1.5 bar
 H = 19.2 m
 air in pump

Pin [W]:
 124.350
Pout [W]:
 ?

Evol :
 ?
Erech :
 ?



rotationspeed (rps): 2.632 **number of rotations :** 2.000
meanflow (dm3/s) : .529 **sample frequency (Hz):** 2631.579

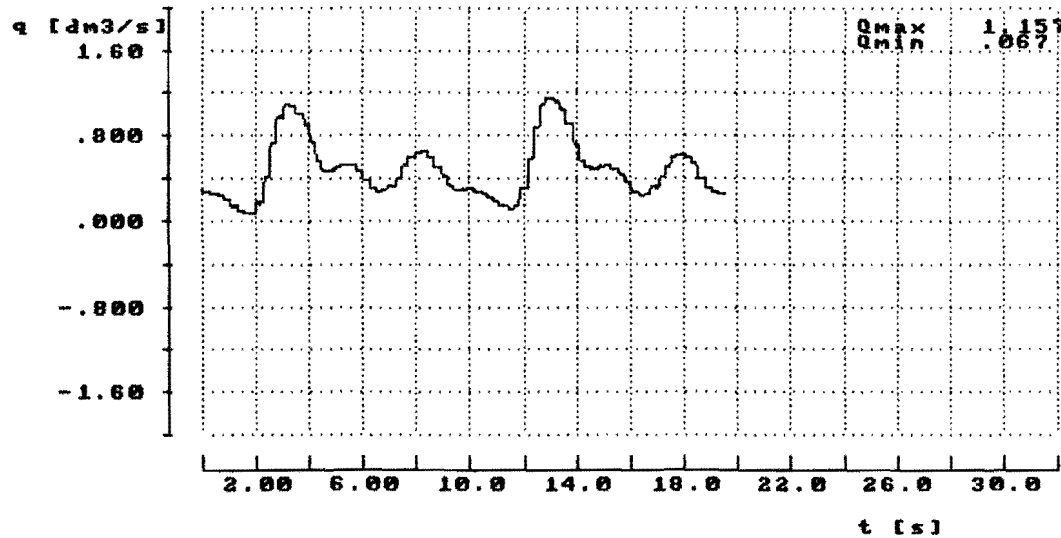


filename --> B:P04924J.

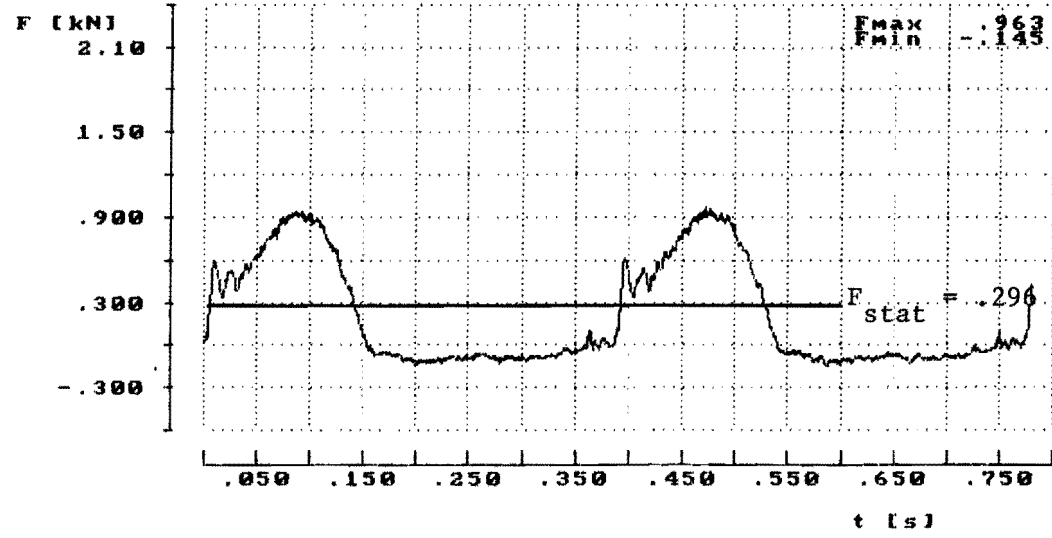
4 holes \emptyset 20
 tube length = 1 m
 $P_{pv} = 1$ bar
 $H = 14.3$ m

Pin [W]:
 115.5
 Pout[W]:
 68.086

Evol :
 .990
 Emech :
 0.589



rotationspeed (rps): 2.564 number of rotations : 2.000
 meanflow (dm3/s) : .479 sample frequency (Hz): 102.459

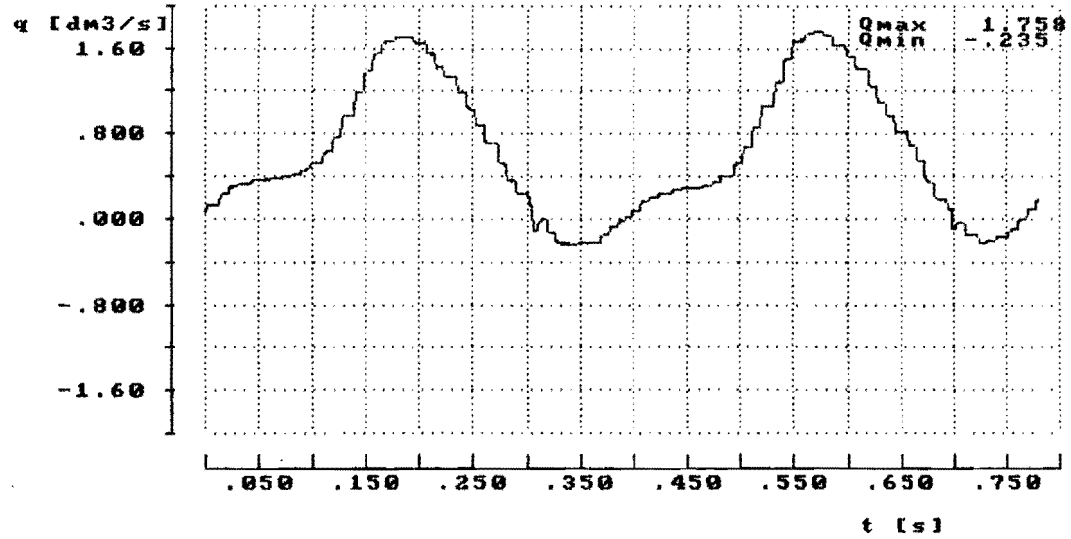


filename --> B:P04923J_

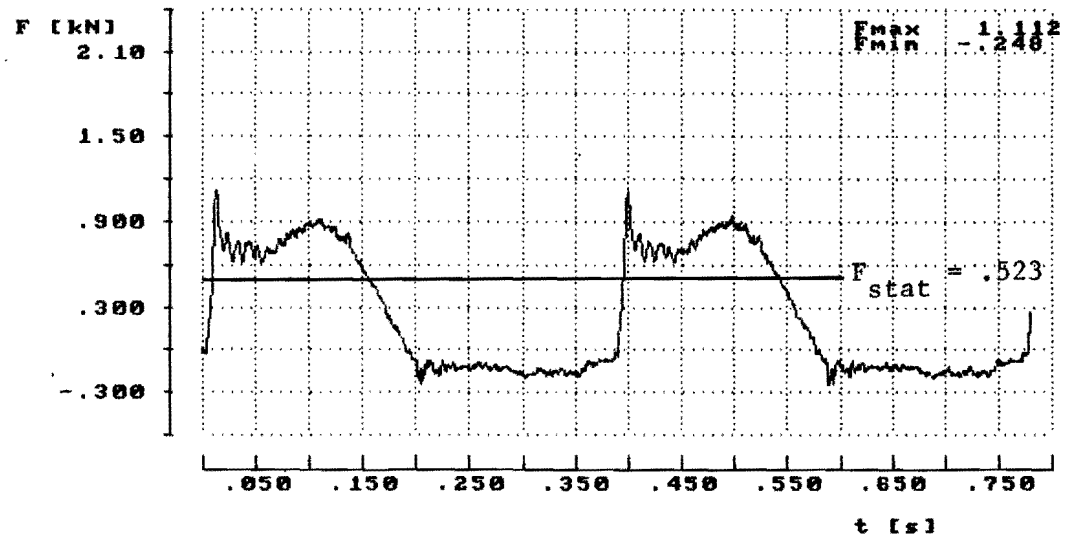
P = 1.5 bar
 H = 19.2 m

Pin [W]:
 173.576
Pout [W]:
 120.814

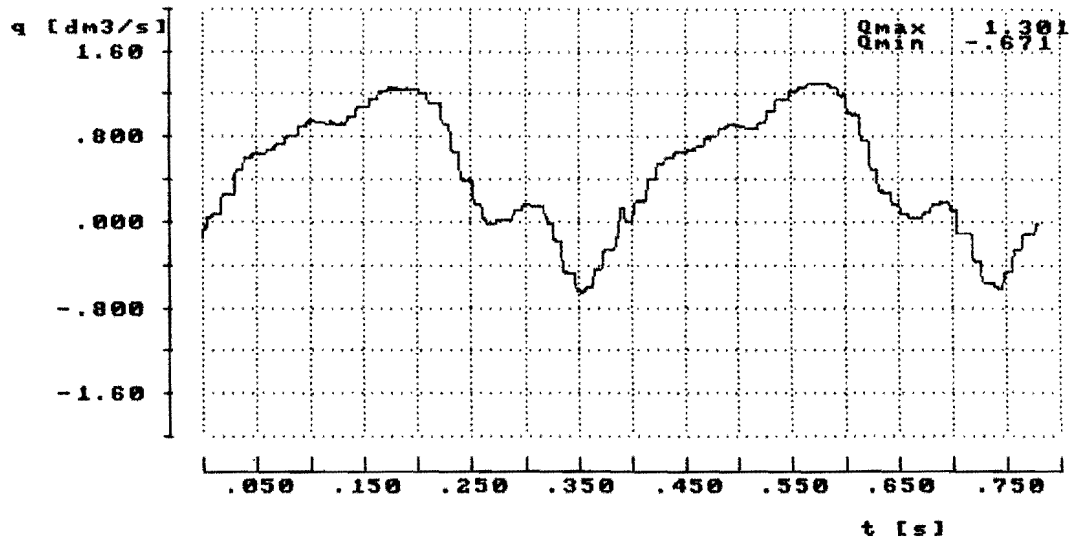
Evol :
 1.274
Emech :
 0.696



rotationspeed (rps): 2.564 **number of rotations :** 2.000
meanflow (dm3/s) : .616 **sample frequency (Hz):** 2564.103



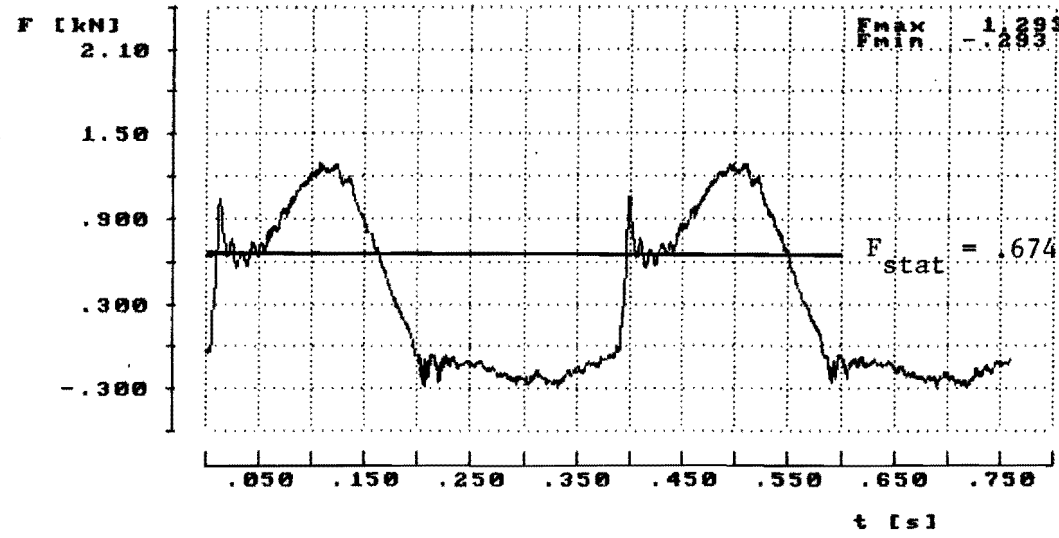
filename --> B:P04925J._



Pin [W]:
 221.641
Pout[W]:
 161.738

Evol :
 .988
Emech :
 0.730

rotationspeed (rps): 2.564 **number of rotations :** 2.000
meanflow (dm3/s) : .478 **sample frequency (Hz):** 2564.103

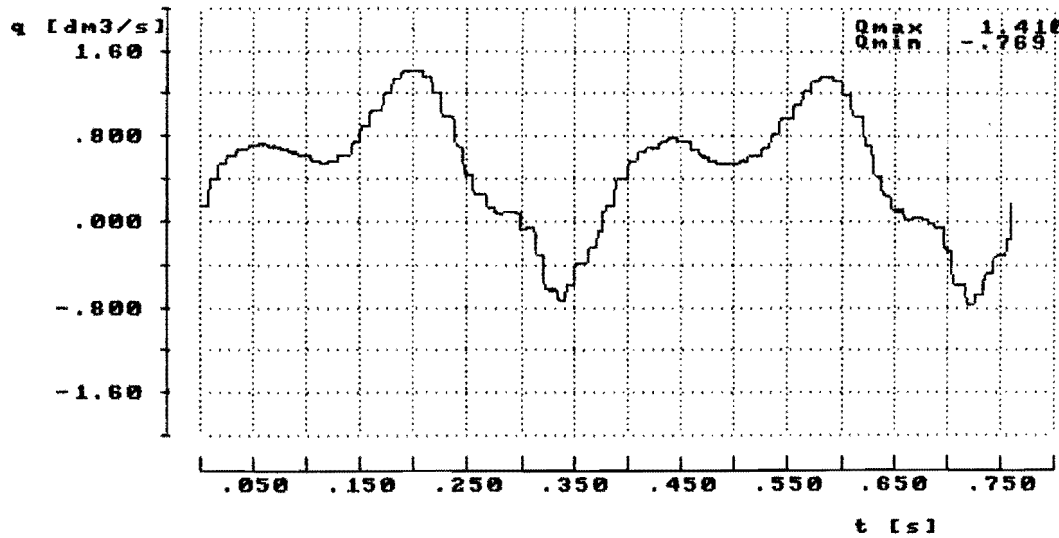


filename --> B:P04926J._

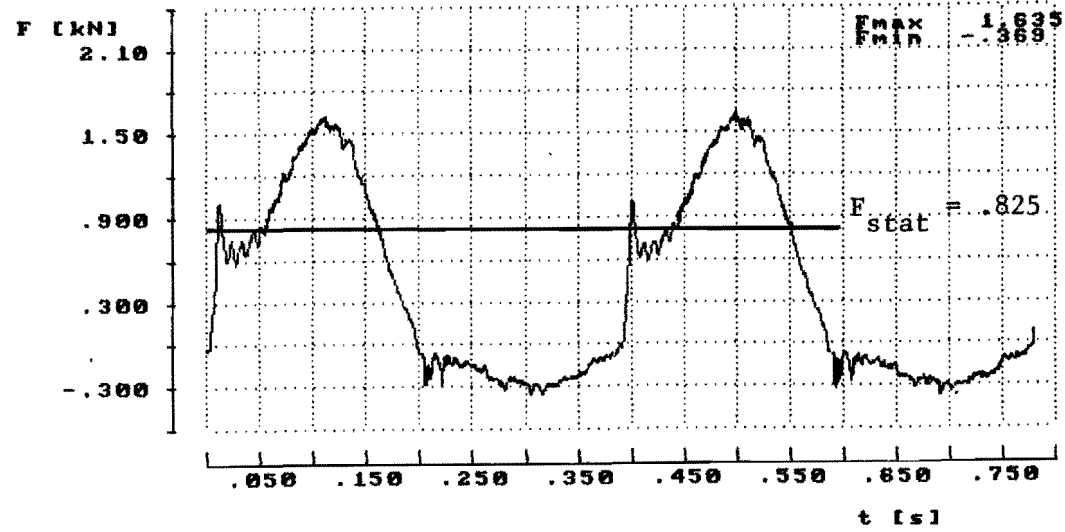
P = 4 bar
 H = 43.7 m

Pin [W]:
 296.098
 Pout[W]:
 204.297

Evol :
 .943
 Emech :
 0.690



rotationspeed (rps): 2.632 number of rotations : 2.000
 meanflow (dm3/s) : .468 sample frequency (Hz): 2631.579

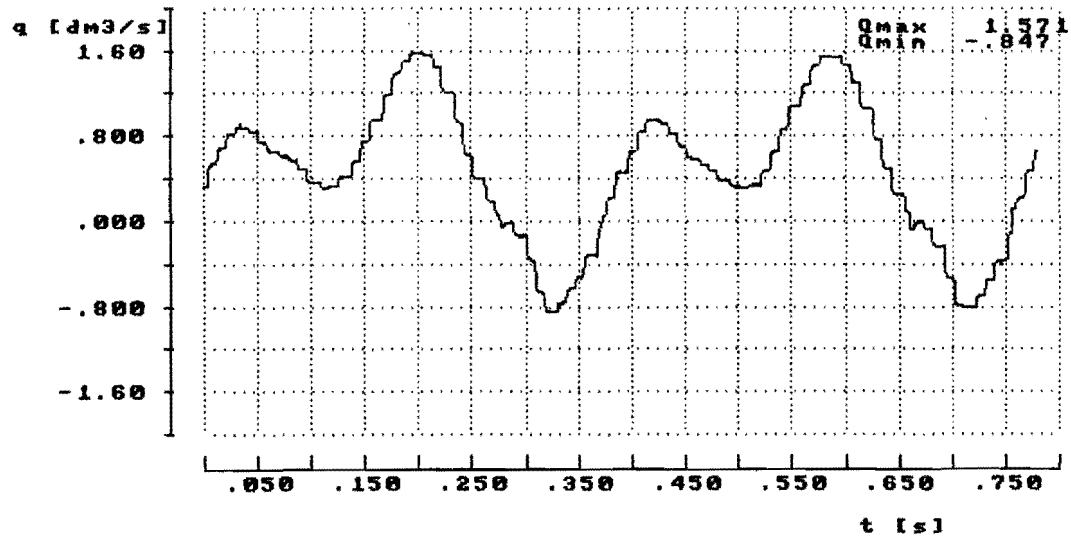


filename --> B:P04927J._

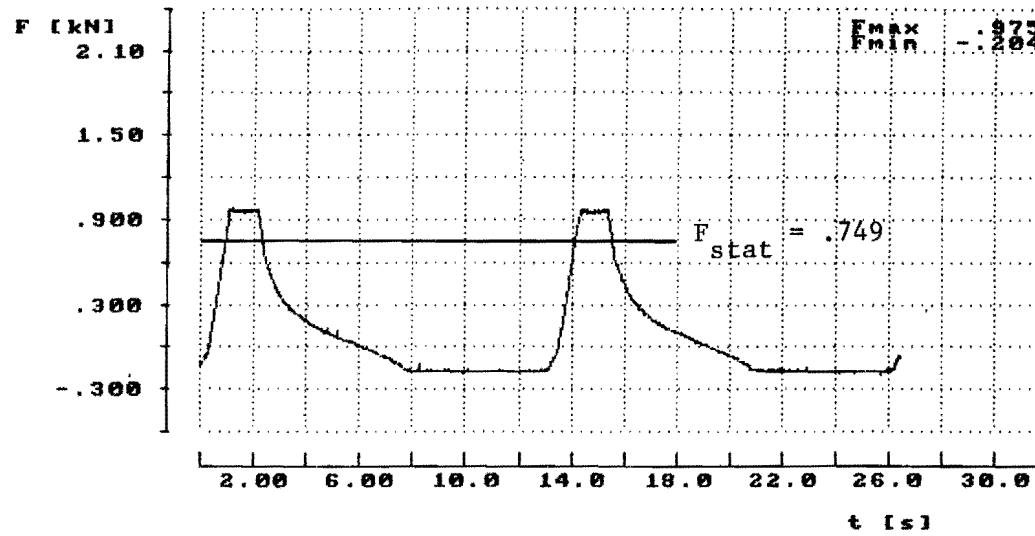
P = 5 bar
 H = 53.5 m

Pin [W]:
 353.8
 Pout[W]:
 247.738

Evol :
 .958
 Emech :
 0.700



rotationspeed (rps): 2.564 number of rotations : 2.000
 meanflow (dm3/s) : .463 sample frequency (Hz): 2564.103

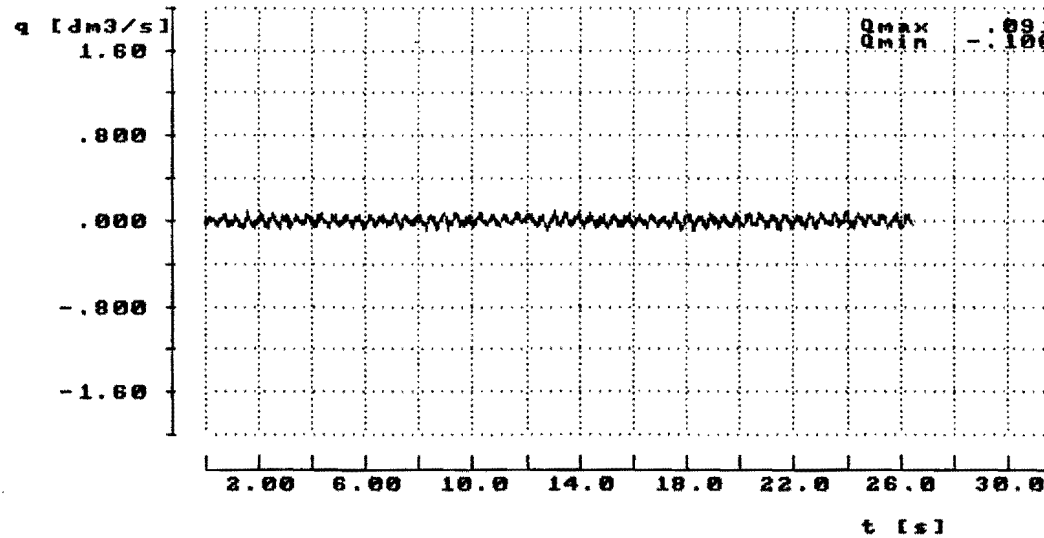


filename --> B:P04929A...

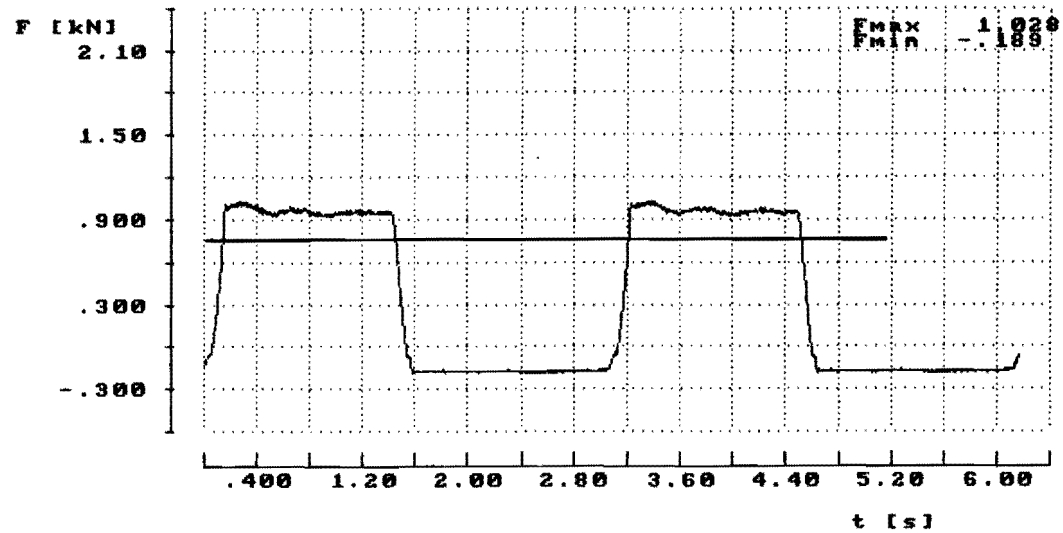
4 holes \emptyset 20
 tube length = 1.45 m
 P_{pv} = 4.5 bar
 H = 48.6 m

Pin [W]:
 5.006
Pout [W]:
 0

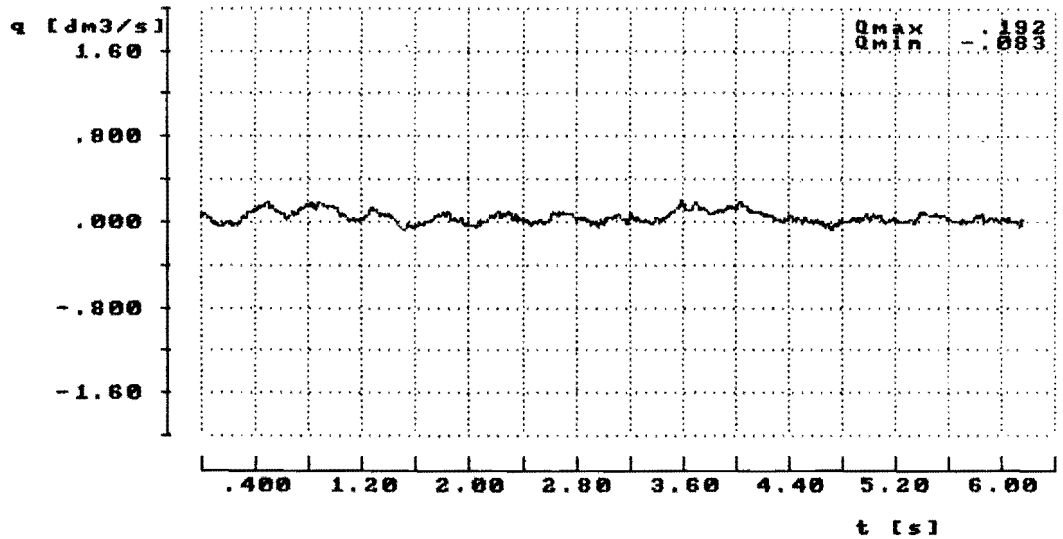
Evol :
 0
Emech :
 0



rotationspeed (rps): .076 number of rotations : 2.000
 meanflow (dm3/s) : -.002 sample frequency (Hz): 75.586



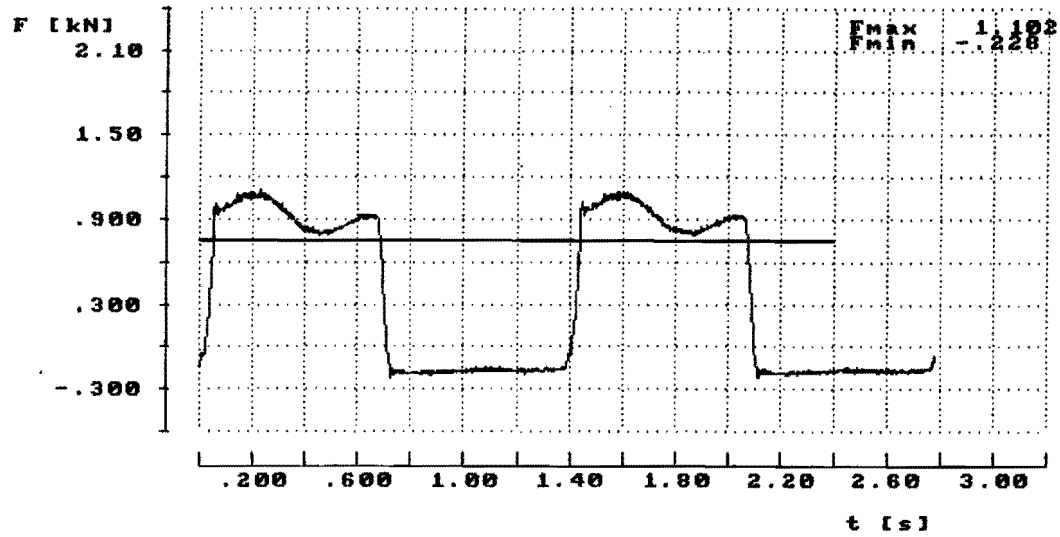
filename --> B:P04929B._



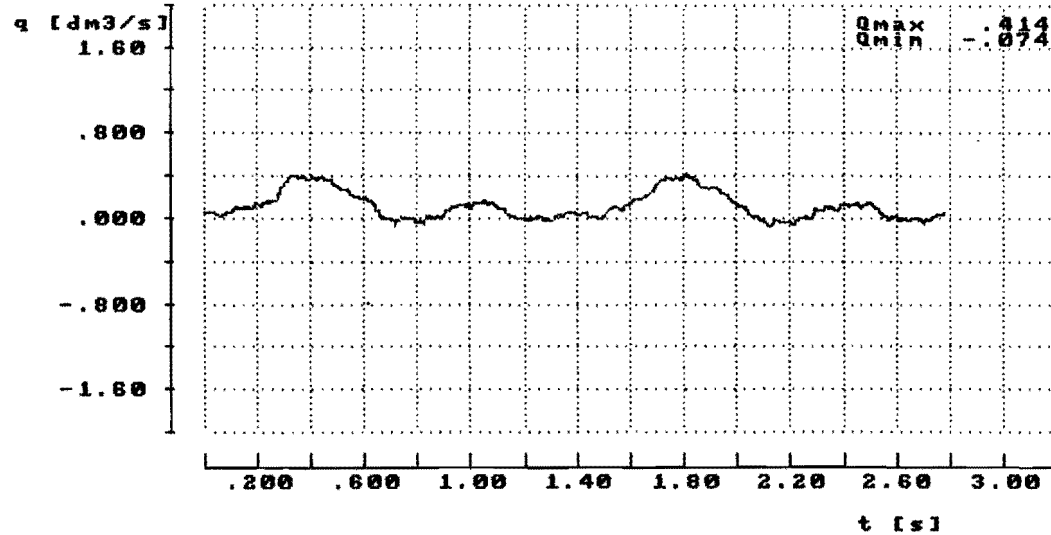
Pin [W]:
36.188
Pout[W]:
19.986

Evol :
.666
Emech :
0.552

rotationspeed (rps): .325 number of rotations : 2.000
meanflow (dm3/s) : .041 sample frequency (Hz): 324.675



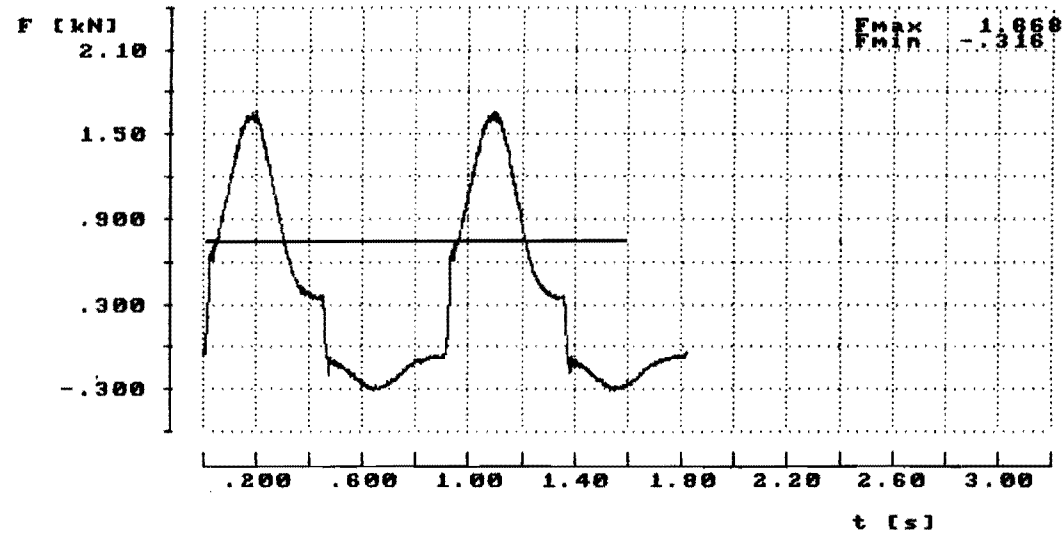
filename --> B:P04929D._



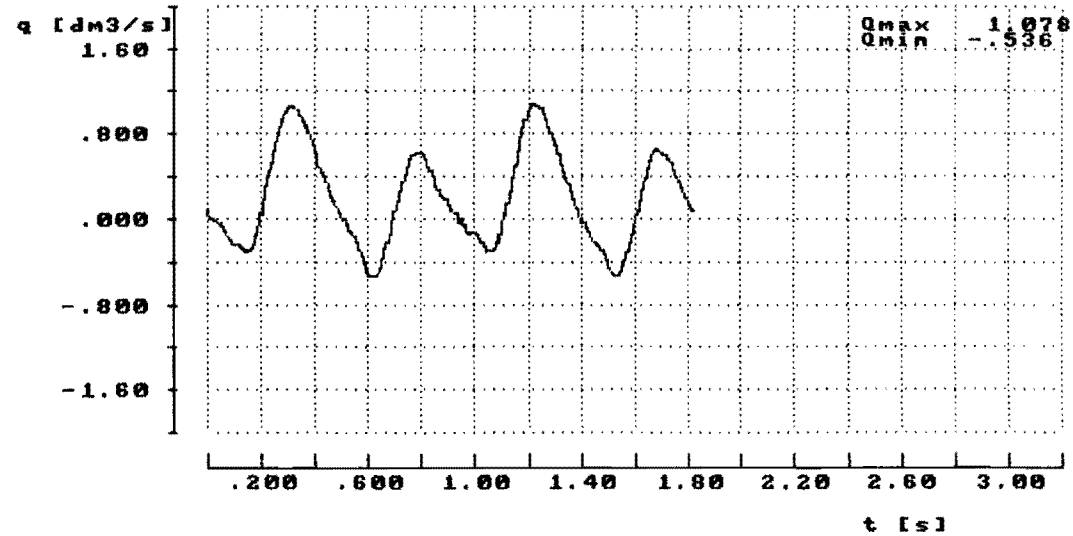
Pin [W]:
78.715
Pout[W]:
55.888

Evol :
.848
Emech :
0.710

rotationspeed (rps): .719 number of rotations : 2.000
meanflow (dm3/s) : .114 sample frequency (Hz): 719.424



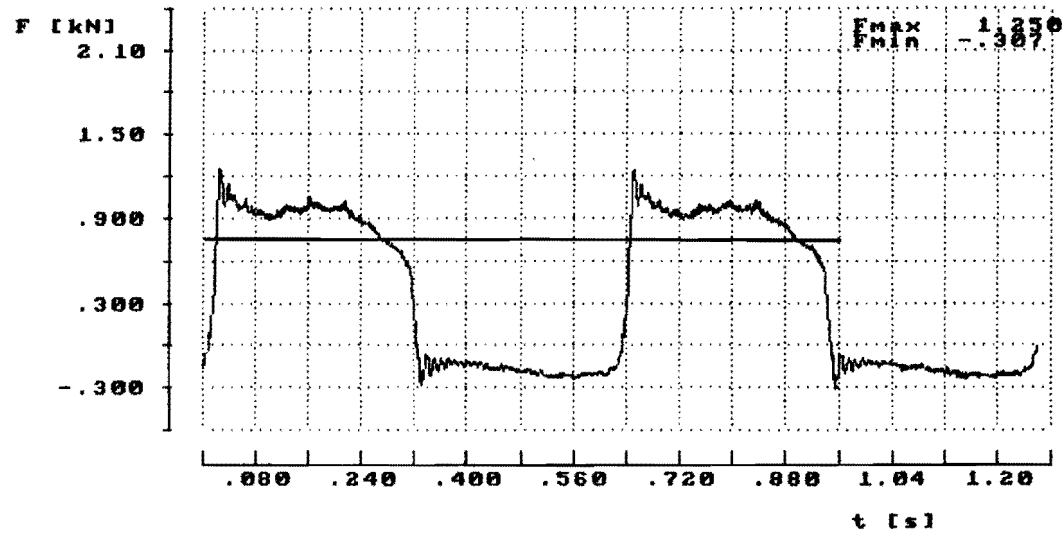
filename --> B:P04929F._



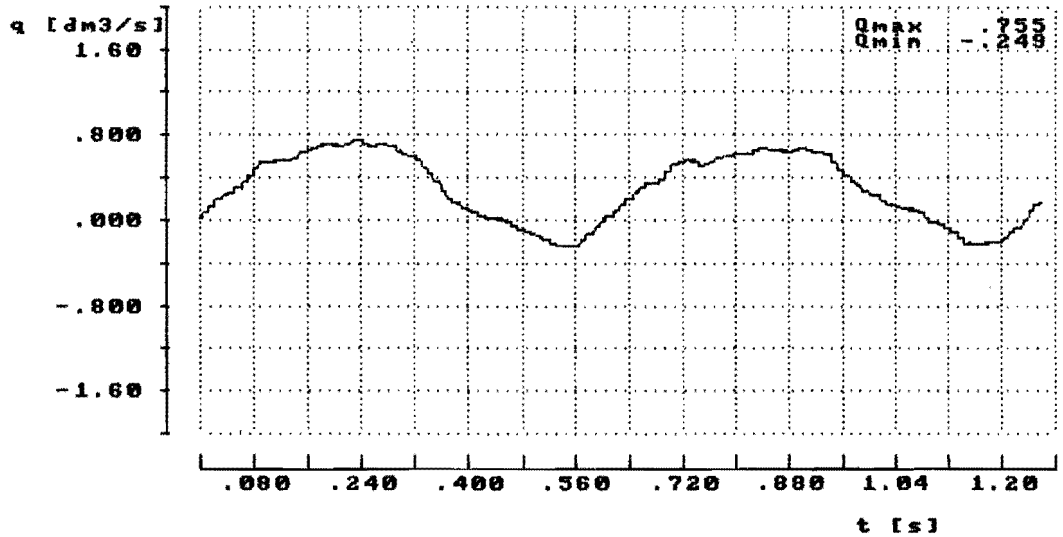
Pin [W]:
 142.808
Pout[W]:
 95.898

Evol :
 .943
Emech :
 0.672

rotationspeed (rps): 1.099 **number of rotations :** 2.000
meanflow (dm3/s) : .198 **sample frequency (Hz):** 1098.901



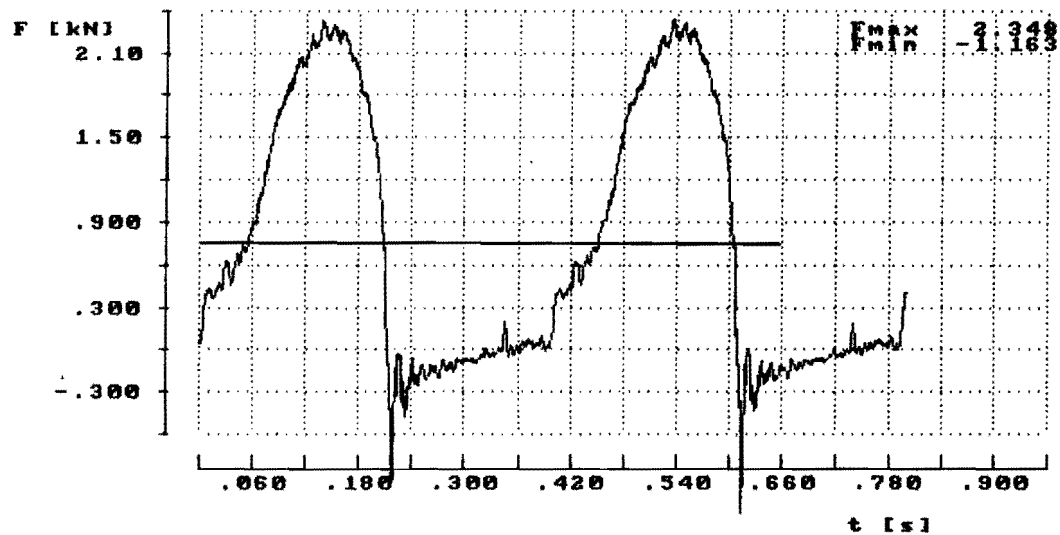
filename --> B:P04929H._



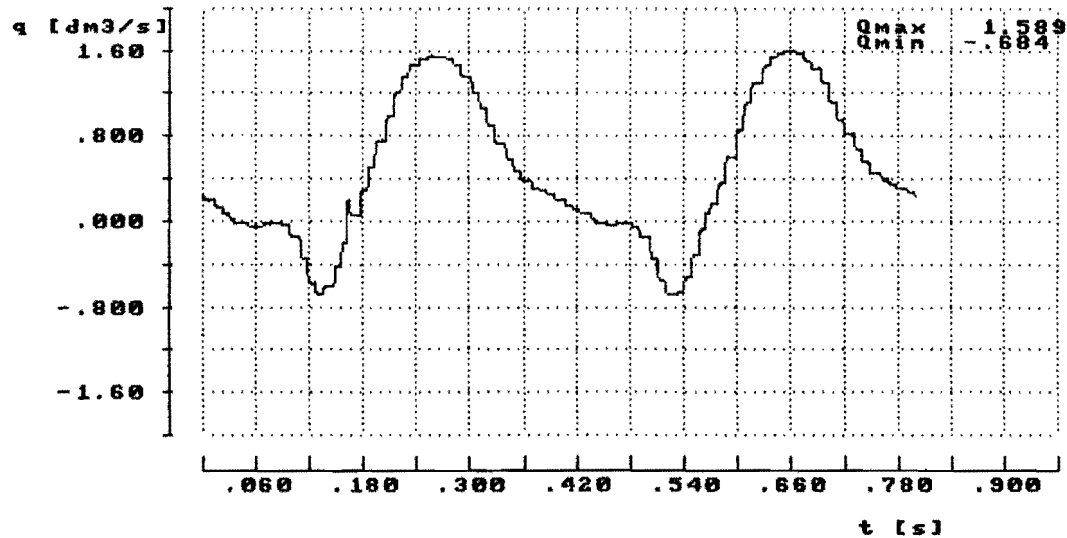
Pin [W]:
 175.067
Pout[W]:
 143.732

Evol :
 .979
Emech :
 0.820

rotationspeed (rps): 1.587 **number of rotations :** 2.000
meanflow (dm3/s) : .293 **sample frequency (Hz):** 1587.302



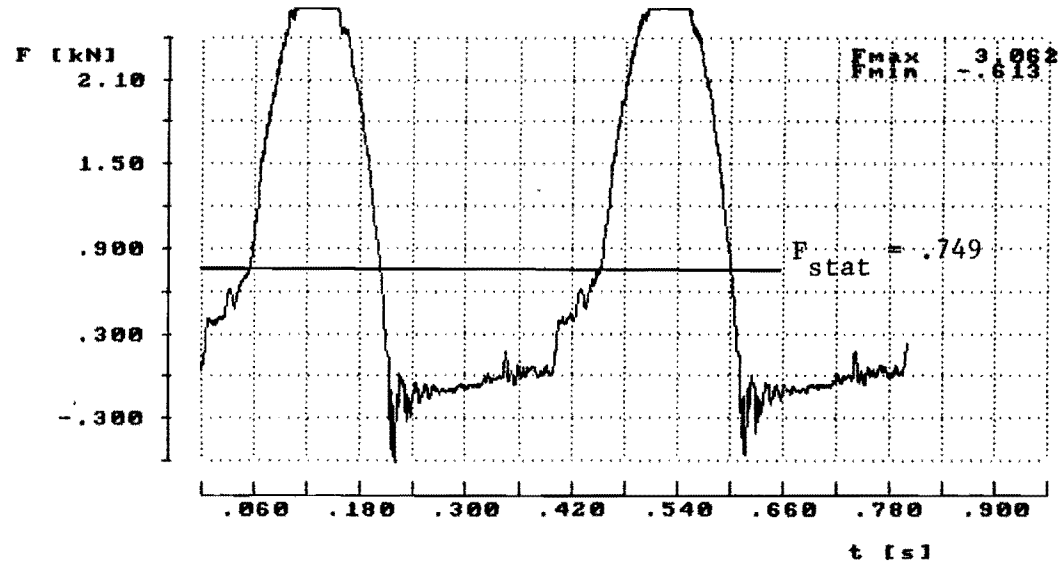
filename --> B:P04929J._



Pin [W]:
 412.416
Pout[W]:
 226.694

Evol :
 .988
Emech :
 0.576

rotationspeed (rps): 2.500 **number of rotations :** 2.000
meanflow (dm3/s) : .462 **sample frequency (Hz):** 2500.000

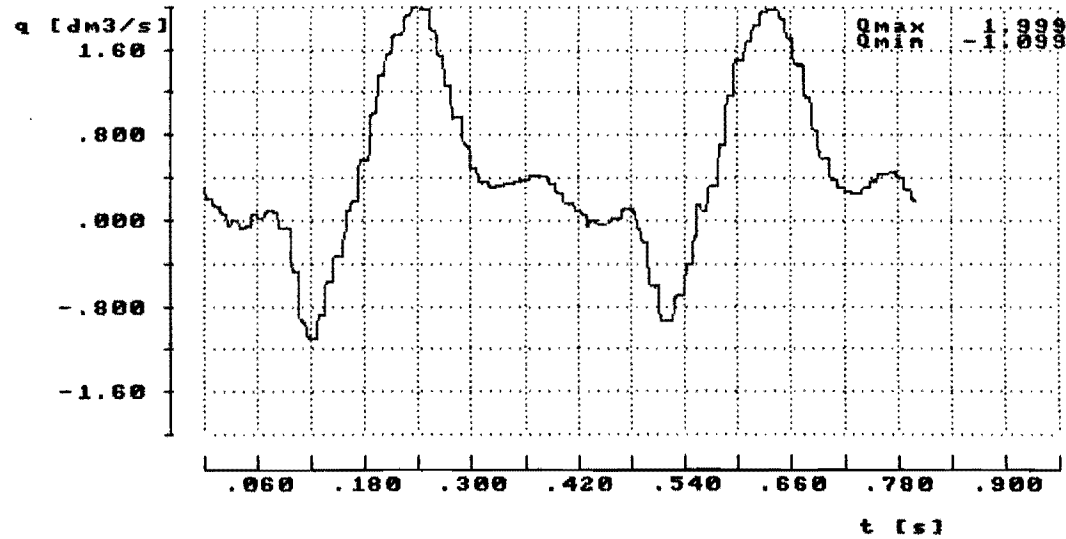


filename --> B:P04930J_

4 holes \varnothing 20
 tube length = 1 m
 $P_{pv} = 4.5$ bar
 $H = 48.6$ m

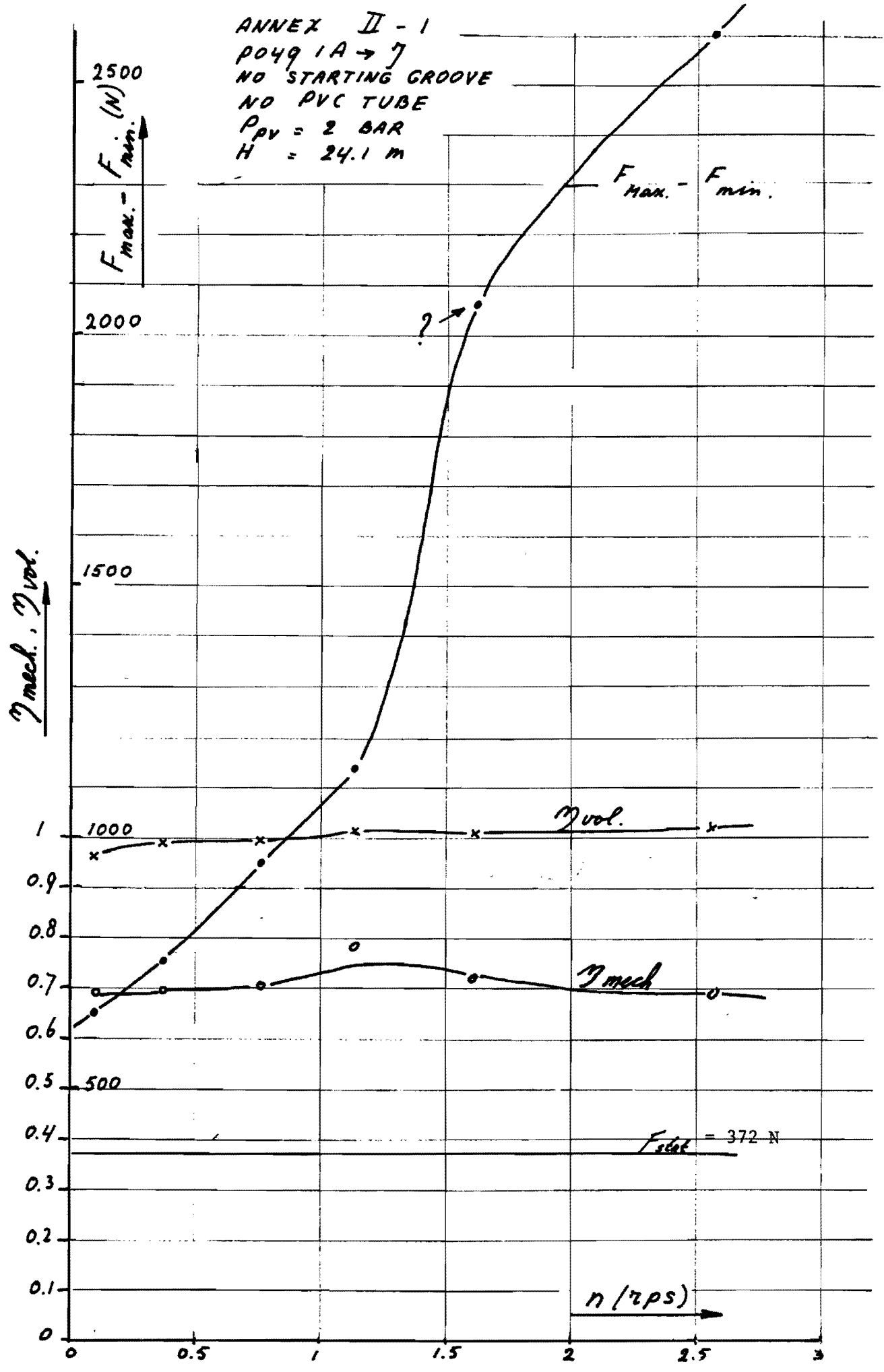
Pin [W]:
 513.155
Pout[W]:
 219.887

Evol :
 .951
Emech :
 0.428

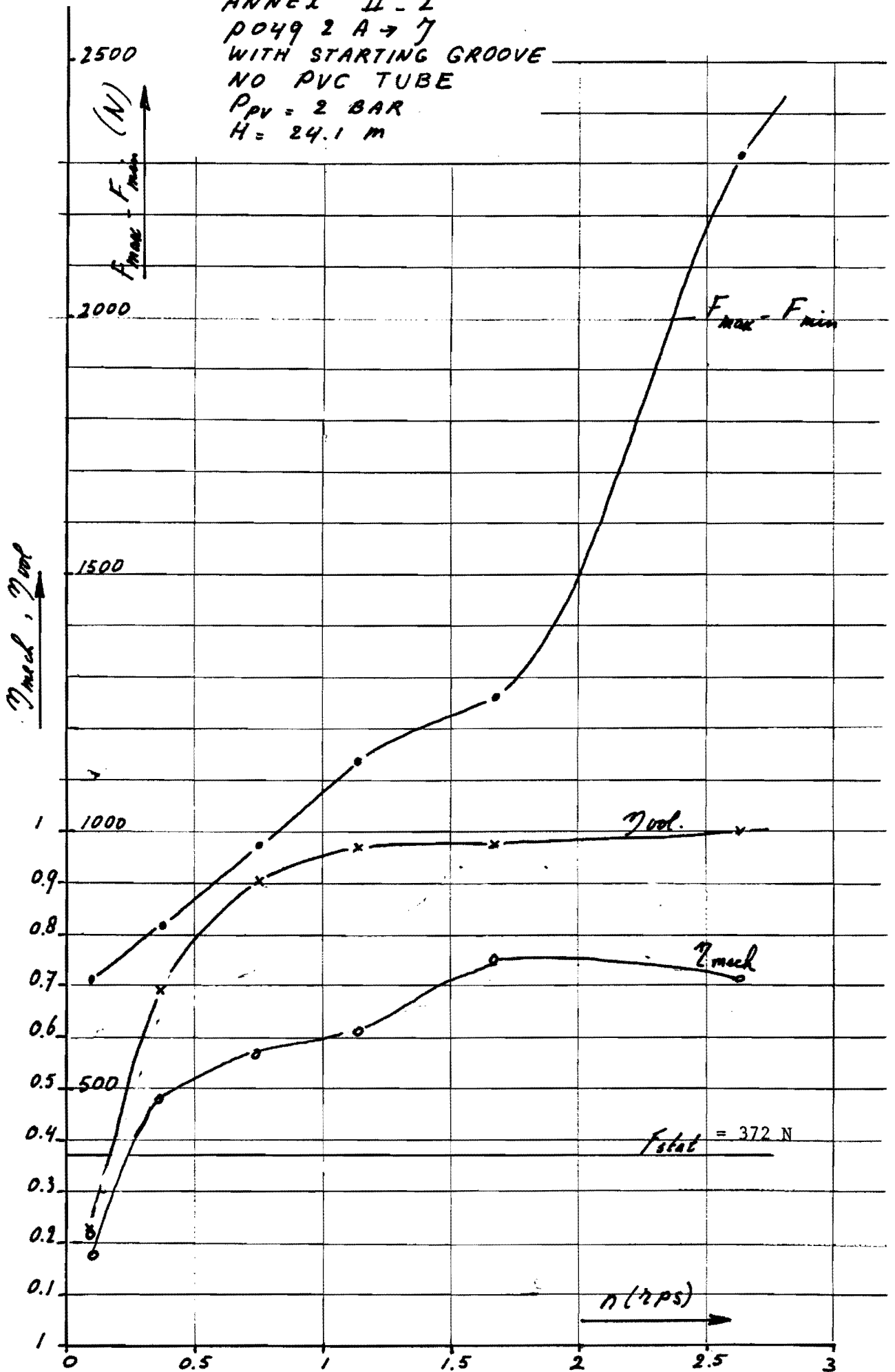


rotationspeed (rps): 2.500 number of rotations : 2.000
meanflow (dm3/s) : .448 sample frequency (Hz): 2500.000

ANNEX II - 1
 P049 1A → 7
 NO STARTING GROOVE
 NO PVC TUBE
 $P_{pv} = 2 \text{ BAR}$
 $H = 24.1 \text{ m}$



ANNEX II - 2
 P049 2 A → 7
 WITH STARTING GROOVE
 NO PVC TUBE
 $P_{pv} = 2 \text{ BAR}$
 $H = 24.1 \text{ m}$



ANNEX II-3
 P049 21 A → 7
 4 HOLES ϕ 20 mm
 TUBE LENGTH = 1 m
 $P_{PV} = 2$ BAR
 $H = 24.1$ m

