



# Start of pump systems

Analysis and calculations



Flygt



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# Start calculation

## 1. Introduction

A start calculation is performed in order to analyse the pump system starting cycle. The starting cycle stretches from the period in time where the system is at rest until the time where steady state conditions have been reached. Current, flow and head are examples of physical quantities which can be plotted as a function of time during the system start up. There are generally no problems when starting a centrifugal pump direct on-line. But it is always good engineering practice to make a start calculation. Axial flow (propeller-) pumps may however have starting problems when they are started against filled systems.

Direct On-line Start (D.O.L.) is generally the best and the most economical starting method. The starting current is however high, it can be as high as 6 times or more than the nominal current. An induction motor can, without problems, withstand the thermal stresses induced by the starting current. But there are cases where a lesser starting current is desired. Such cases are:

- Weak power supply. The high current at a direct on-line start may affect other electric equipment connected to the grid.
- Local regulations. Some regions or areas require reduced current start for all pump installations.

There are several methods to reduce the starting current:

- Star/Delta start
- Auto-transformer
- Solid state soft starter
- VFD – Variable Frequency Drive

The first three methods are examples of commonly used starting methods. All three methods control the voltage and hence available motor torque during the start up phase. Variable speed drive, VFD, is normally not used solely as a starting device. A VFD is mainly used to improve process control. The VFD has a positive side effect in that it can be set to reduce the starting current. The use of VFD as a starting method will not be analysed here.

FLYGT has developed a method to analyse the starting process. This method has been incorporated in a computer program called SPAS – Start of Pump Against System. A key feature of the SPAS program is its ability to account for the acceleration of the water column when analysing the starting process. This yields more accurate results than most methods found in handbooks etc. This program also calculates settings/switch times for soft starters, auto-transformers and star delta start. See section 4 for more information.

## 2. Basic theory

The three first techniques described above regulates the voltage during the speeding up of the pump/motor. Both motor torque and current are proportional to the square of the voltage:

$$\frac{T}{T_{nom}} \approx \left(\frac{U}{U_{nom}}\right)^2 \quad \frac{I}{I_{nom}} \approx \left(\frac{U}{U_{nom}}\right)^2$$

The relationship between actual voltage and rated voltage is denoted as tapping.

The load of a centrifugal pump is suitable for start with reduced voltage. There is normally no initial load when the pump is started and the load will increase proportionally to the square of the speed. The basic idea when starting a pump with some kind of starting method is to reduce the motor torque in the beginning of the start-up phase when the load torque is small. This is done by reduction of available voltage. A lower motor torque corresponds to a lower starting current. The switch over to line voltage (100 % tapping) is normally done when the nominal speed for the selected tapping has been reached. The motor has at this stage almost reached full speed and it can be seen from fig 2.2 that the current for nominal voltage is quite low.

The lowest possible tapping is determined by the load curve and the motor torque curve. The motor can not accelerate (speed up) if the load curve intersects the motor curve. The switch over will be at too low speed and this will result in a high starting current, see fig 2.5 and 2.6. A margin of 15 % between load torque and available motor torque during start-up is recommended. The shape of the load torque curve is determined by the system and the available accelerating torque. This implies that the load curve is different for different drive units and different tappings. I.e. the same system with the same pump but with different motors and/or tappings has different load curves.

A too early change over will lead to an increased starting current. It can be seen from fig 2.6 that the current hasn't dropped sufficiently before the change over, the maximum starting current will be 370 A. This should be compared to the case with optimum switch over time (and same tapping) where the maximum starting current was 220 A (See fig 2.3, 2.4).

A too late change over implies that the motor will be running with reduced voltage during a period of time when the load is almost the same as full load. The motor will be under magnetised and the efficiency will drop. This leads to a temperature rise in the stator windings. The motor will, after some running time, be over heated and the thermo-contacts will trip. The motor can however withstand this for a short time period, but the motor should not be run for more than 5 seconds with reduced voltage. There are also other reasons why a delayed switch over time is undesirable, see the sections about start of different systems for more details.

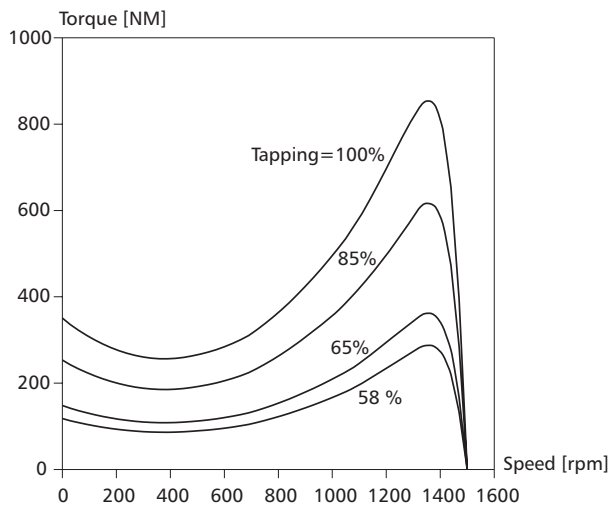


Fig 2.1 Torque curves for various tappings.

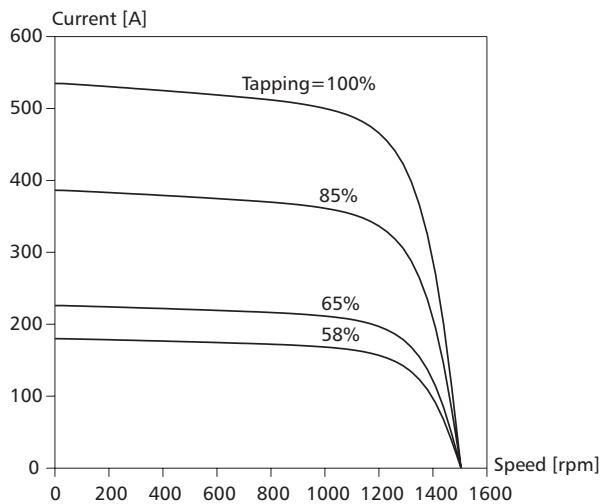


Fig 2.2 Current curves for various tappings.

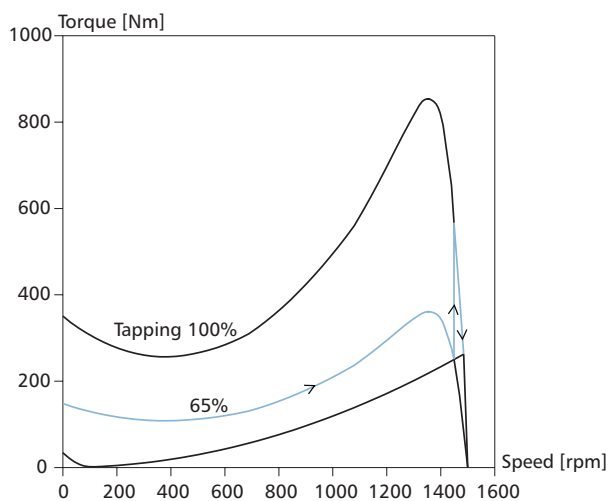


Fig 2.3 Torque during starting cycle with 65 % tapping. Optimum switch over time.

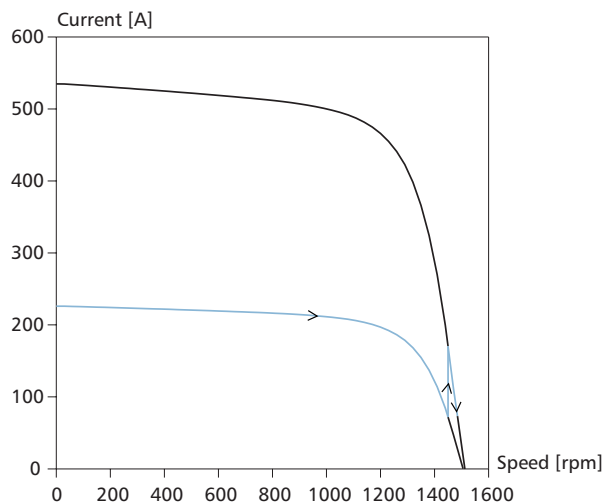


Fig 2.4 Current during starting cycle with 65 % tapping. Optimum switch over time.

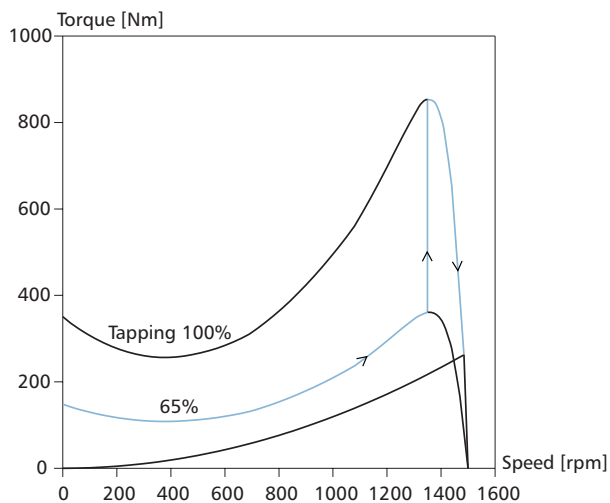


Fig 2.5 Torque curve at too early change over.

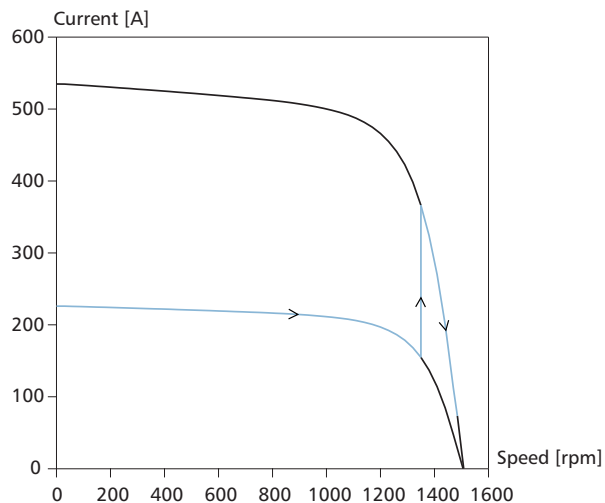


Fig 2.6 Current, too short switch time.

## 2.1 Star / Delta start

The motor is during the accelerating of the pump/motor connected in star configuration. The voltage on each phase is  $\frac{1}{\sqrt{3}}$  times nominal voltage. The available starting torque is a third of nominal starting torque. The starting current is also reduced by a factor of 3. The switch over to delta connection is, as described above, done close to nominal speed. This starting method requires, of course, that the motor is connected in delta connection in continuous duty.

One drawback with the star/delta start is that the switch over is done mechanically. The switch over can not be done faster than about a 1/10 of a second. The pump/motor will during this short period loose speed. The effect can in some cases be the same as a too early switch over, i.e. only a minor or no current reduction. Another drawback is the fact that the motor requires an extra set of power leads. One set when running in star connection and one set when running in delta connection.

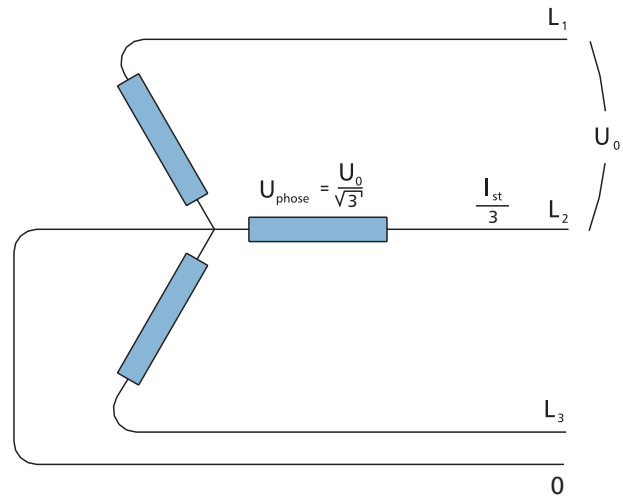


Fig 2.7 Star connection.

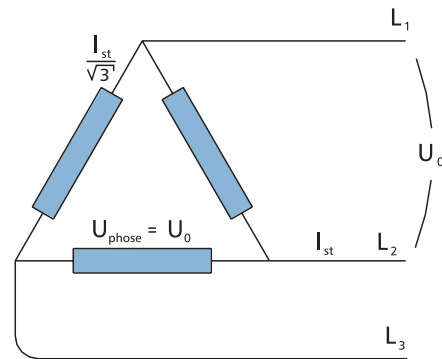


Fig 2.8 Delta connection.

## 2.2 Auto transformer start

The Auto transformer is a switchable transformer. The transformer has several secondary connections on the windings called tapings. Normal standard tapings are 58 % (same as start/delta), 65 %, 75 % and 85 %. The pump starts with a reduced voltage (one of the standard tapings) and will after a preset and adjustable time switch over to line voltage (100 % tapping).

## 2.3 Soft starter start

The voltage control for the solid state soft starter is not done in pre-defined steps as with the auto transformer, the voltage changes more continuously. The soft starter works with constant acceleration, i.e. the difference between available motor torque and load torque is constant. The soft starter matches the load torque with a slightly higher motor torque.

### 3. Start of pump against system

The time to start a pump system can be divided into 2 parts:

- The time for the pump to reach nominal speed
- The time for the system to reach steady state conditions, final duty point

The time it takes for the pump to accelerate (speed up) depends on the polar moment of inertia for the rotating parts and the accelerating torque. The accelerating torque is defined as the difference between available motor torque and load torque, see fig 3.1. The time it takes to reach nominal speed is depending on the size of the motor, but normal acceleration times are 0.1 s for small motors and up to 1 s or more for larger ones. The time it takes until the system has reached the final duty point is considerably longer. This time can be from a couple of seconds up to a minute or longer for very large systems.

The intersection between the load torque and the motor torque, (1), is the duty point when the pump has reached its full speed. It is however not the duty point when the system has reached its final duty point. See example in section 3.1 for a more detailed explanation. The full speed duty point, (1) can not easily be determined, it depends on the system and

the accelerating torque. The duty point has to be calculated with a numerical algorithm. The full speed duty point (1) can for certain cases be estimated. Many of the methods mentioned in handbooks are based on such estimations. This will however not yield a correct result which is a necessity when determining switch times.

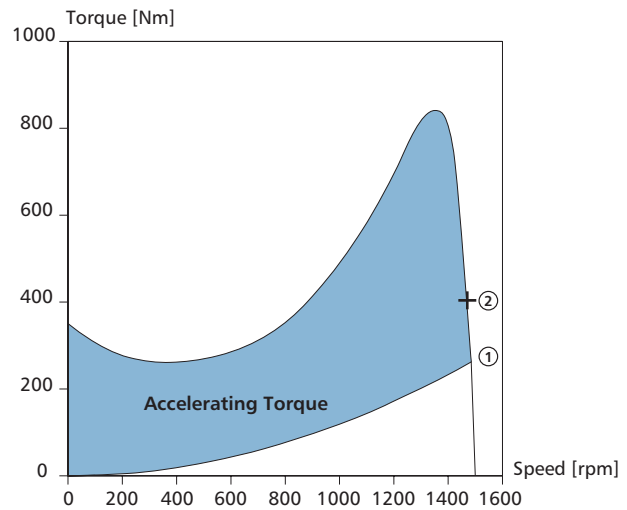


Fig 3.1 Accelerating torque during start up.

#### 3.1 Start of centrifugal pump, filled system

It is generally possible to start a centrifugal pump direct on line against a filled system. This application is also suitable for start with reduced tappings.

The torque characteristics for a centrifugal pump are well suited for start against filled systems. The power consumption is low for low flows and increases with the flow. See power curve in fig 3.2.

The pressure head during pump acceleration will not follow the system curve due to the inertia in the system. No flow will be delivered until the pump has reached the speed where the shut-off head is greater than the static head. A small amount of water will be pumped when the static head is exceeded. How much is depending on the volume of the system, but the full speed duty point will for most systems be quite close to shut-off head (1). It can be seen from the figure that the start-up pressure head curve will meet the

nominal performance curve when the shaft power is low. This implies that the load torque is low. The duty point will then move down along the pump curve until the system has reached steady state conditions, i.e. the final duty point at the intersection between the pump curve and the system curve (2). The difference between the start-up pressure head curve and the system curve is the acceleration pressure (head). The two points, full speed duty point (1) and final duty point (2), can also be found in the torque diagram (fig 3.1) with the same denotation. The start-up time for the system is proportional to the volume of the system.

This implies that :

$$T_{\text{start-up}} \sim L$$

$$T_{\text{start-up}} \sim D^2$$

Where  $L$ =length of discharge pipe and  $D$ =diameter of discharge piping.

When running multiple pumps in a system with a common force main the worst case is not when the first pump is started (system in rest). The system is

### 3 Start of pump against system

already in motion when an additional pump is started, more water will be pumped during the speeding up phase. The full speed duty point (1) will move to the right towards higher flow. The power out take at this

point is higher than at the duty point for the start of the first pump. The power at the full speed duty point, (1), will determine the load torque at full speed, (1) in fig 3.3. The load curve will hence be higher.

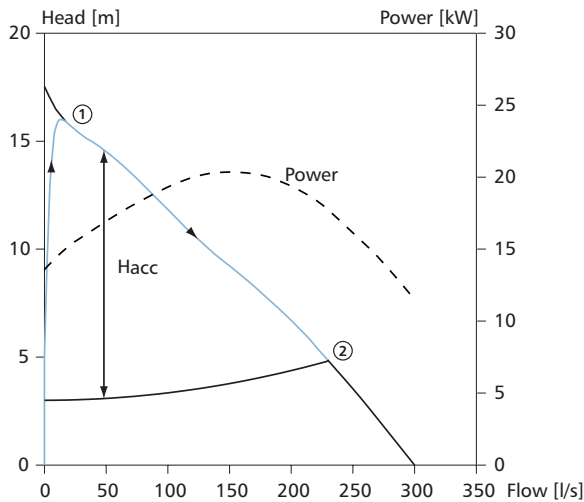


Fig 3.2 Start up sequence for a centrifugal pump started against a filled system.

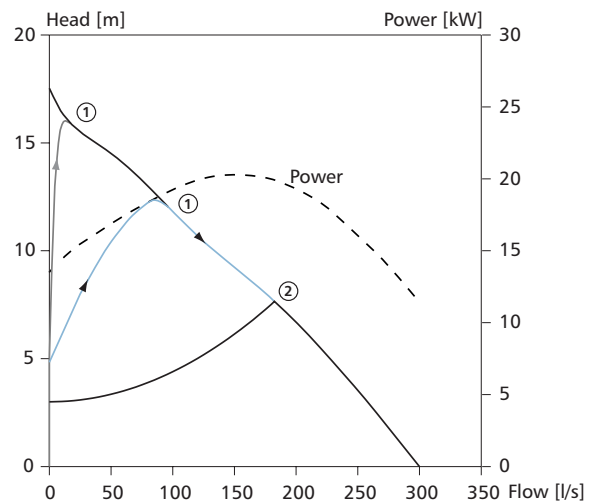


Fig 3.3 Start of a second centrifugal pump in a multi pump system.

(1) Duty point at full speed, system not at rest.

(2) Final duty point, system at rest.

\* Picture exaggerated.

## 3.2 Start of centrifugal pump, empty system

Start of a centrifugal pump against an empty system is not as favourable as a start against a filled system. There are however no problems to start the pumps direct on line, but it can be difficult to find a low enough tapping which the system can be started with. There is no static head and no water to accelerate when the pump is started. A head will be built up due to the acceleration in the system. Furthermore the static head will increase during the start cycle. The static head will reach its final value when the pipe is filled.

A high acceleration pressure head will be created during the speeding up phase. This is due to the rapid acceleration of the empty system. The pressure head curve during start up will meet the pump curve at a point where the flow and hence the power is high (2). A high power in the full speed duty point implies that the load curve will be steep and it will be hard to find low tapplings to start the system with. The pump has reached it's nominal speed at the point (1) and the acceleration will be zero. the acceleration head will

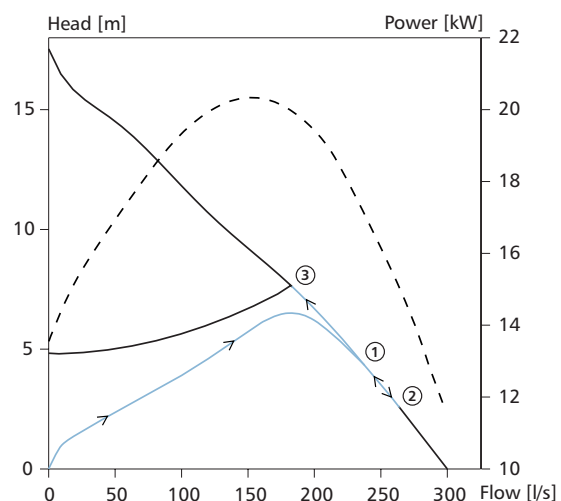


Fig 3.4 Start of a centrifugal pump against an empty system.

diminish and the duty point will move down along the pump curve. The duty point will then turn at point (2) and start to move upwards, when the static head is increasing. The final duty point (3) will be reached when the pipe is filled.

### 3.3 Start of propeller pump, filled system

Start of propeller pumps against filled systems are in general not feasible. It can even in some cases be impossible to start the system direct on line. A propeller pump has opposite power characteristics than a centrifugal pump. The power is high at low flows (high head) and will decrease at higher flows. The pump curve consists of two parts. One part, at high flow and low head, where the pump is designed to operate at and a part, close to shut-off head, which is unsuitable for continuous operation. In between there is an unstable region where the propeller stalls.

The start-up cycle is similar to the cycle for start of a centrifugal pump against a filled system. There is however a major difference, the head during start-up will meet the nominal pump curve (1) where the power is at a high level. The torque during the start up will be very high and it can in some cases be problems to start the system. The motor is designed for the operational part of the curve, i.e. the motor will be overloaded when running at the upper part of the curve. The power at shut-off head can be as high as 2 times higher than the rated power.

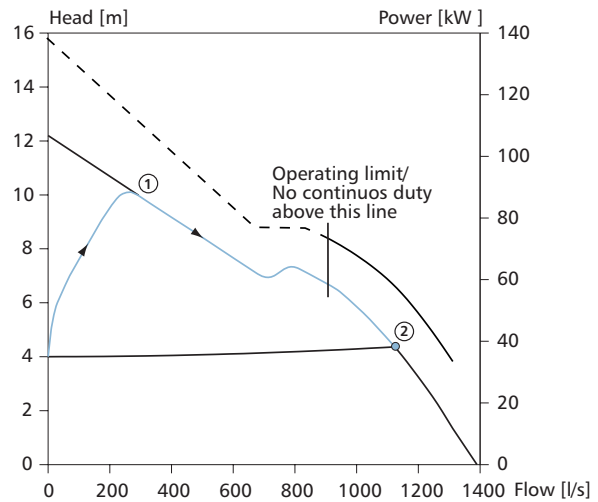


Fig 3.5 Start of a propeller pump against a filled system.

### 3.4 Start of propeller pump, empty system

This is the best and the recommended way to start a propeller pump. The start-up cycle is similar to the cycle for start of a centrifugal pump against an empty system. There is however a difference, the pressure head during start-up will meet the nominal pump curve (1) where the power is low.

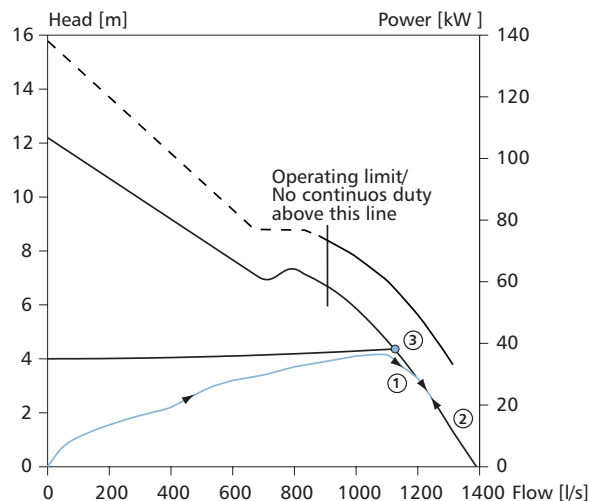


Fig 3.6 Start of a propeller pump against an empty system.



## 4 SPAS – A computer program for start analysis

The SPAS program, Start of Pump Against System, can calculate the start-up sequence for both D.O.L. start and start with different tapplings (i.e. star/delta, auto transformer and soft starter). If the tapping is unknown the program will calculate and recommend suitable tapplings for the selected starting method and optimise for minimum starting current.

4 different outputs/printouts are available from the program:

### ■ System specification

- Product
- Pipe system
- Start tapplings

### ■ Various parameters as function of time

- Head
- Flow
- Speed
- Load torque
- Voltage
- Current

### ■ Torque and current as a function of time

### ■ Head during start up displayed in QH-diagram

Contact your local FLYGT office for a customised start calculation on your system.

The information needed to make a start calculation is:

### ■ Complete product denomination

- Product type
- Product installation
- Motor number  
E.g. 43-30-4AA 138 kW
- Motor rating
- Stator number
- Line voltage
- Line frequency

### ■ Suction and discharge pipe system

- Diameter, length and elevation for each pipe section
- Inlet and outlet water levels
- Pipe material (used roughness factors, loss coefficients)
- Duty points

### ■ Start method

- D.O.L.
- Star/Delta
- Auto-transformer  
Available tapplings
- Soft starter

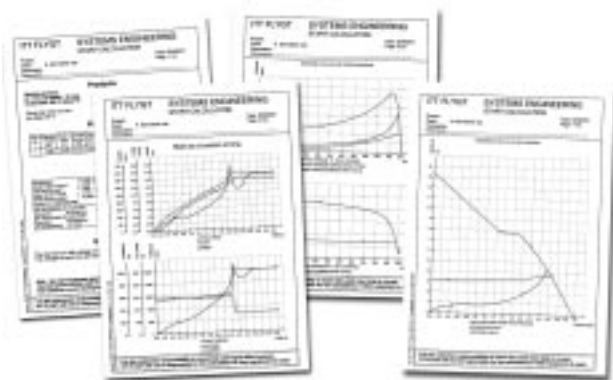


Fig 4.1 Output/Printouts from the SPAS program.



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