Engineering & Expertise Transient Analysis

START CALCULATIONS

FLYGT

a xylem brand

Total solution engineering increases operational efficiency

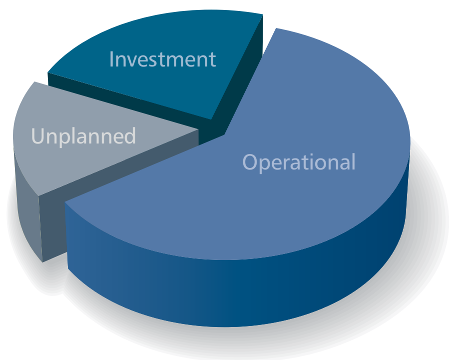
Introduction

Being able to predict the performance of a pump during its startup cycle has distinct advantages. Among them are more reliable starts, optimal startup torque, and minimal risk of motor overload. It is therefore considered good engineering practice to analyze the pump system's starting cycle. By performing start calculations using an accurate mathematical model of the system, we determine optimal system pressures and flow rates at startup.

Performing such theoretical analysis on pump systems requires engineering and expertise. We will provide guidance for optimizing pump starting cycles using our system expertise and product knowledge to conduct thorough theoretical analysis of the pump systems using specially developed engineering software.

Achieving lowest total cost of ownership

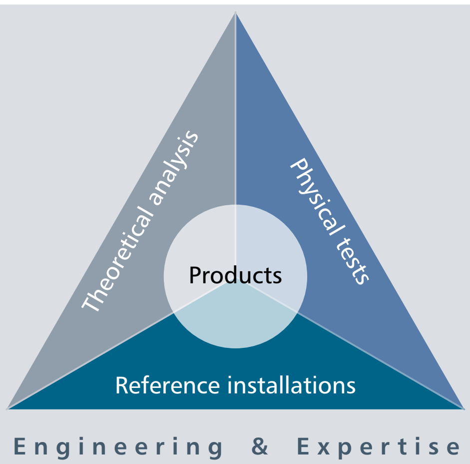
When providing pumping solutions, Flygt prefers to take the total cost of ownership into consideration.



■ *Investment costs*
Costs associated with design, excavation, civil work, product purchases, installation, and commissioning.

■ *Operational costs*
Over time, energy usage and maintenance costs are the largest contributors to the total cost of ownership.

■ *Unplanned costs*
When things go wrong, such as pump failures stemming from problematic station design, costs can skyrocket. Unexpected downtime can cause sewer backups, overflows, basement flooding, and untreated effluent. On top of that, you have to repair pumps and take corrective measures regarding the station design.



Engineering & Expertise

Thanks to our engineering expertise, we can lower your total cost of ownership. We can analyze your system using state-of-the-art computational programs. We can test your pump station using scale models if required. We can also provide you with reference installations that are similar to your project. All of this together with our premium products provides you with an optimized design.

Start calculations: Hydraulic transient analysis

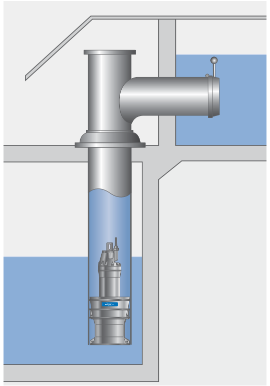
When dimensioning and designing a pump system, it is important to analyze the influence of the starting conditions on the pump system during transient operation. Transient operation is the period of time between two steady state conditions; in this case, the time period between pump at rest and pump in operation.

When starting the pumps there are three different characteristics that should be evaluated: motor torque and power, magnitude of the starting current, and hydraulic analysis of filling the pipes.

Motor torque and power
Analyzing the motor torque is important to make sure that the pump has sufficient motor torque to accelerate the fluid at startup. Problems may be encountered, for example, when starting a propeller pump in a system with check valve, such as a pipe system filled with water. Therefore when designing a filled system with propeller pumps, it is highly recommended that a start calculation be performed.

The motor of the pump can experience overload during startup. Centrifugal pumps are sensitive to startup when the system is empty. Propeller pumps are sensitive to startup when the pipe system is filled. When designing a system that is not preferred for the pump type, a start calculation should be performed.

Hydraulic analysis of filling the pipes
In some systems, it is essential to know how the pipes are filled at startup. A start calculation provides a good indication of how the pipes will be filled.


Filled system with propeller pumps.

Magnitude of starting current
The typical starting current is about six times the rated current. A high starting current will affect weak power grids and the dimensioning of the installed fuse. High starting currents could be reduced through the use of different types of start equipment: star-delta starters, soft starters, and variable frequency drives (VFDs). When using a starting method other than direct-on-line (DOL), it is recommended that a start calculation be performed.

Achieving lowest total cost of ownership
Flygt start calculations help optimize hydraulic performance. These calculations reduce the risks associated with insufficient starting torque and insufficient motor torque. They may also lower investment, operating, and maintenance costs by correctly dimensioning start equipment, preventing motor overload, and using the lowest possible start current. This results in more reliable starts, longer-lasting motor and pump station components, and thereby the lowest total cost of ownership.

Understanding the startup sequence

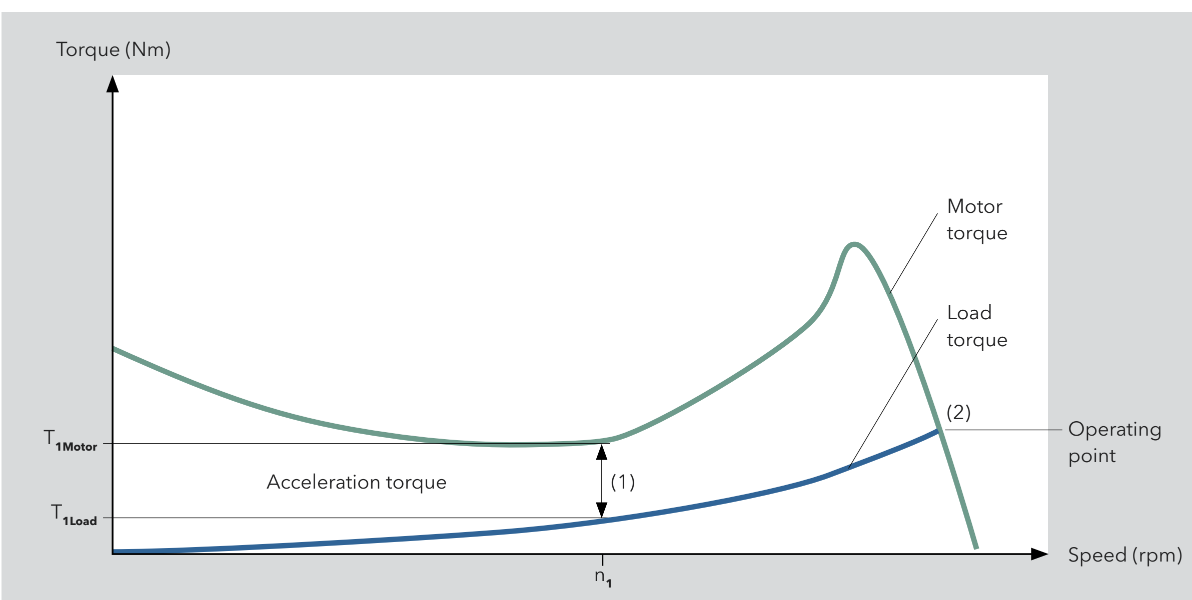
To optimize performance and prolong equipment service life, Flygt both designs and manufactures submersible motors for our own pumps. We therefore have complete knowledge of the motor characteristics and are able to perform precise analysis of the startup sequence.

Starting up the hydraulic system in order to reach the duty point of the pump can be divided into two distinct moments in time: the motor start and the hydraulic system start.

Motor start
To determine motor start, it is necessary to understand the motor torque given by the motor characteristics and the load torque given by the system load. The load torque in a pump system may be approximated to a quadratic load. The distance between motor and load torque is the accelerating torque (1). The point at which the motor torque and the load torque intersect provides the operating point of the motor (2). When starting a pump direct on line, it generally takes less than a second to accelerate the impeller to the nominal speed.

Hydraulic system start
To determine startup of the pump system, it is necessary to understand the pump performance given by the hydraulic characteristics of the pump and the system curve given by the system characteristics. The system curve in a pump system may be approximated to a quadratic load. The point at which the motor torque and the load torque intersect provides the system duty point.

A system may either be started with an empty pipe system or with the pipe system filled with fluid. In a filled pipe system, sufficient pressure must be generated in order to start accelerating the fluid inside the pipe. When the fluid has reached sufficient acceleration, the pressure will be reduced until the duty point is reached. In an empty pipe system, the flow will initially increase and then the pressure will be built up due to the losses in the pipe system and the static head. The flow will thereafter decrease until the duty point is reached. Actual system startup times vary between a few seconds for systems with short pipelines and several minutes for systems with long pipelines.



Motor start: Accelerating torque (1) and operating point of the motor (2).

Motor torque and power

Sufficient motor torque

There is a great risk of insufficient motor torque during the start sequence of a propeller pump in a system filled with fluid. The pump will then stall and, in the worst-case scenario, the motor will burn. Having a pump installed with insufficient motor torque will result either in replacement of motor unit or the rebuilding of the system; both scenarios are very costly.

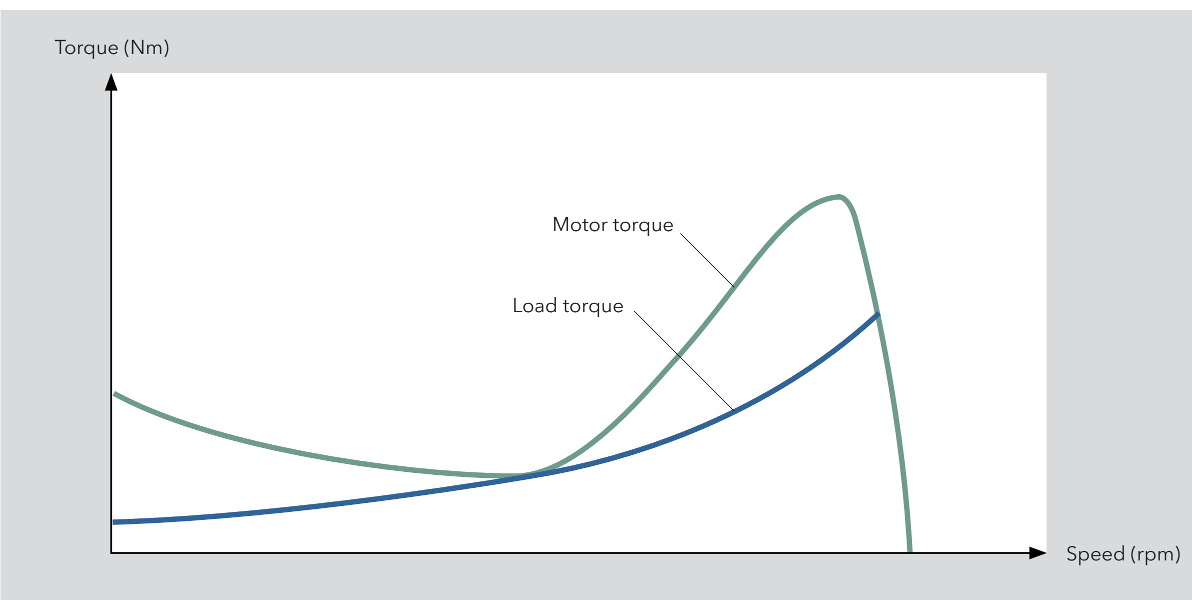
When starting a propeller pump at low flow and high head, the torque margin between motor and load will be very small and sometimes insufficient. Using start methods, such as a star-delta starter or soft starter, will decrease the motor torque and make the startup even more problematic in filled systems. A start calculation must be performed on propeller pump systems that will be started with a filled system.

Starting a propeller pump in an empty system is generally not a problem; however, when using a star-delta starter or soft starter, the motor torque is reduced and a start calculation is recommended.

Magnitude of starting power

The performance characteristics of centrifugal pumps result in a power curve that increases with the flow; that is, when the pump is delivering high flows, the motor is operating at high power. Starting a centrifugal pump in an empty pipe system will result in the pump operating at high flow to the right of the curve. If the pump has a power limitation on the curve, the motor may be overloaded.

The performance characteristics of a propeller pump result in a power curve that decreases with the flow; that is, when the pump is delivering low flows at high head, the motor is operating at a high power. The propeller pump is therefore sensitive to startup in a pipe system filled with water not only from a torque perspective but also from the perspective of overloading the motor. The pump is generally only overloaded for a couple of seconds at most. A short overload such as this will not damage the motor immediately, but if the overloading is sufficiently high and lasts long enough, frequent overloads will decrease the motor's lifetime. The motor manufacturer should be contacted if the pump is overloaded.



Motor curve intersects with load curve resulting in no acceleration torque.

Hydraulic analysis

The startup sequence will vary depending on the type of pump and whether the system is filled or empty. It is therefore important to know the pump type as well as the system conditions when considering the startup sequence.

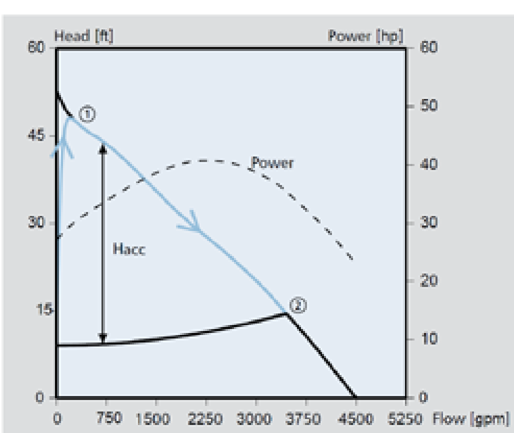
Centrifugal pumps

Startup with the system filled
The torque characteristics for a centrifugal pump are well suited for startup against filled systems. The pressure head during pump acceleration, however, will not follow the system curve because of the inertia in the system.

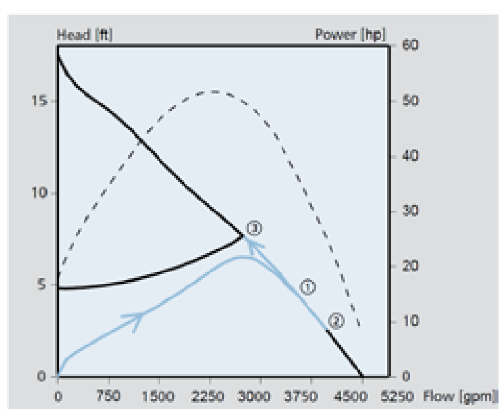
No flow will be delivered until the pump has reached the speed where the pump head is greater than the static head in the example below at ~3 m. The startup curve will meet the performance curve when the power is low (1). This implies that the load torque is low. The pressure will then accelerate the flow until the duty point is reached (2).

Startup with the system empty
Startup of a centrifugal pump when the system is empty does not present as favorable of conditions as when starting up with a filled system. Direct on line starts of an empty system will not present any problems. However, any other starting method should be analyzed to identify any potential problems. Pressure will build up due to the acceleration in the system. Furthermore the head will increase during the start cycle and reach its final value when the pipes are filled.

The acceleration phase contributes to the creation of a high acceleration head. This is due to the rapid acceleration of fluid in the empty system. The path during startup will intersect the pump curve at a point where the flow, and, therefore, the power is high (1). The pump has reached its full speed at this point, and the pump acceleration will be zero. The flow will continue to increase due to a positive acceleration head, which begins to diminish once point (1) is reached. From point (1), the operating point will move along the pump curve to point (2), where the acceleration head is zero. The operating point will then turn at point (2) and start to move upwards when the static head increases. The final duty point (3) will be reached when the pipes are filled.



Startup sequence for a centrifugal pump with a filled system.



Startup sequence of a centrifugal pump with an empty system.

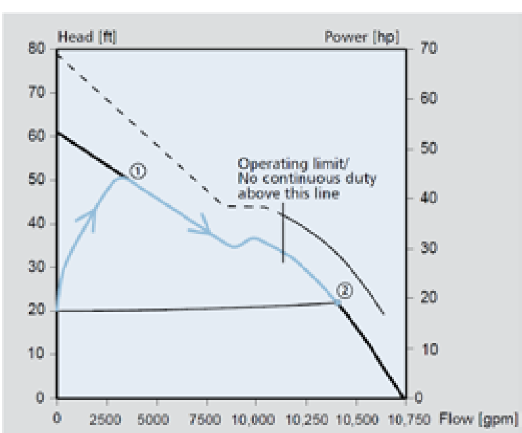
Propeller pumps

Startup with the system filled
Generally speaking, it is not feasible to start propeller pumps when the system is filled. In some cases, it may even be impossible to start the system using direct-on-line starters.

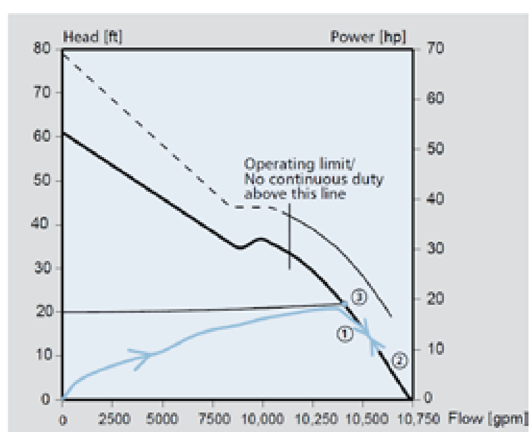
A propeller pump has exactly the opposite power characteristics of a centrifugal pump; power is high at low flows and will decrease at higher flows. The propeller pump curve typically consists of two parts. The first is at high flow and low head, which reflects the conditions under which the pump is designed to operate. The other, shown as a dotted line the figure below, is close to the shutoff head, which is unsuitable for continuous operation. In between these two points lies an unstable region of operation where the propeller stalls.

The head during a propeller pump startup will intersect the performance pump curve (1) where the power is at a high level. The torque during the startup will be very high and, in some cases, can result in problems in starting the system. The motor is designed for the operational part of the curve and will be overloaded when running at the upper part of the curve. The power at shutoff head may be as much as two times higher than the rated power.

Startup with the system empty
Starting propeller pumps when the system is empty is the recommended start method for these types of pumps. Here again, the startup cycle is similar to that of centrifugal pumps when starting up with an empty system. Despite the similarities, there is also a major difference: the pressure during startup will meet the nominal pump curve (1) where the power is low.



Startup sequence of a propeller pump with a filled system.



Startup sequence of a propeller pump with an empty system.

Selecting the correct motor startup method

Normally the starting current is about six times the rated current. The motor is designed to withstand the high start current and is suitable for a direct-on-line (DOL) start. However, for various reasons described below, the start current may need to be reduced, especially for large motors. It is often important to know the exact value of the start current in order to configure the start method, size the backup power generators, and dimension motor protection. In order to identify the start current and size reliable start equipment, a start calculation is needed.

Direct-on-line start

As described above, the DOL start is generally the most reliable and economical starting method. However, the use of a DOL start may not be appropriate, in some cases, due to requirements for a lower starting current when conditions such as these exist:

- Weak power supply: The high current required for a DOL start may affect other electrical equipment connected to the grid.
- Local regulations: Some regions or areas require a reduced starting current for all pump installations.
- Lower voltage fuse: The use of a lower voltage fuse design is sometimes required in an effort to reduce operating costs. However, this approach generally requires a lower motor torque and subsequently a lower load torque and lower starting current.
- Generator backup: Generators must be dimensioned to cope with a higher current than the operational current.

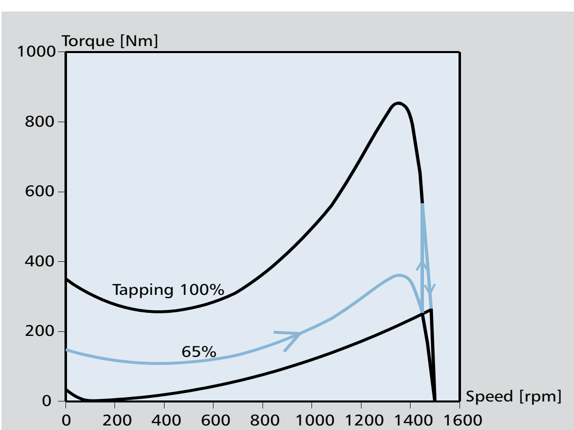
The basic idea when using some type of starting method is to reduce the motor torque at the beginning of the startup phase when the load torque is small. This can be accomplished by reducing the available voltage. Both the motor torque and the current are proportional to the square of the voltage; therefore, a lower torque corresponds to a lower starting current. The relationship between the actual voltage and the rated voltage is referred to as tapping.

Star-delta starter

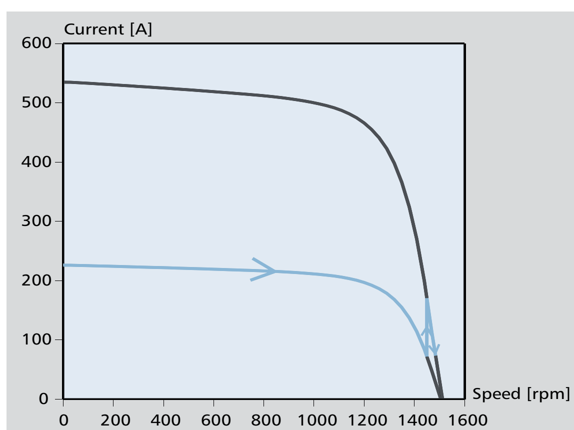
During pump acceleration, the motor is connected in star configuration. The voltage on each phase is $1/\sqrt{3}$ times the nominal voltage. The available starting torque is one-third of the nominal starting torque. The starting current is also reduced by a factor of 3. The changeover from star to delta connection is normally accomplished as close to full speed as possible. This starting method naturally requires the motor to be designed for delta connection continuous duty.

A drawback with the star-delta starter is that it requires mechanical changeover, which takes approximately one-tenth of a second to complete. During this time, the motor will lose speed, and the current may not be reduced as required. Another drawback is that the motor requires an extra set of power leads – one set used in star connection and the other set used in delta connection.

The changeover to line voltage (100% tapping) should occur once the nominal speed for the selected tapping has been obtained. At this stage, the motor has almost reached full speed and the current for nominal voltage is quite low.



Torque curve at optimum changeover.



Current curve at optimum changeover.

A changeover that occurs too early increases the starting current. The graph (on page eight on the left side) shows optimal changeover where the maximum starting current was only 220 A. The graph (below) indicates that the current has not dropped sufficiently before the changeover; the maximum starting current will be 370 A.

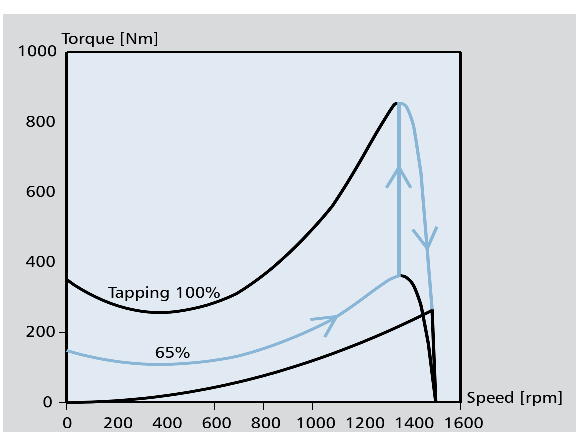
The lowest tapping is determined by the motor load curve and the motor torque curve. If the load curve intersects the motor curve, the motor is not able to accelerate. Changeover will then occur at a speed that is too low, which will result in a high starting current. The system and the available accelerating torque determine the shape of the load torque curve. This implies that the load curve varies when using different drive units and different tappings. In other words, although the system and the pump are the same, the use of different motors and/or tappings changes the shape of the load curves.

Soft starter
A soft starter limits the starting current and starting torque during startup. With the use of phase control, voltage is reduced during startup and is subject to continuous, but gradual, change in order to ensure a perfect match between the load torque and a motor torque that is slightly higher. By gradually increasing the voltage in small increments, it provides a smooth acceleration thereby ensuring that the difference between available motor torque and load torque is constant.

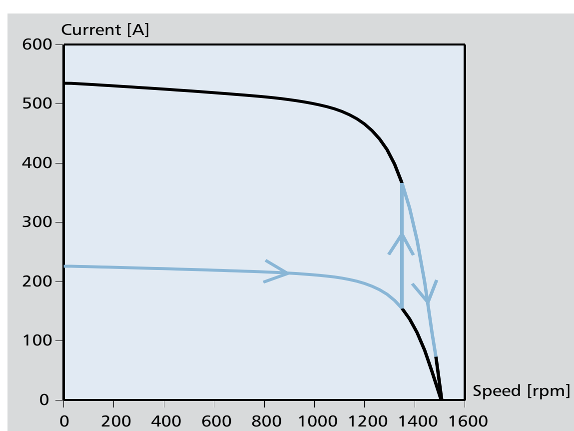
A soft starter is more expensive than direct-on-line starters, but less expensive than variable frequency drives.

Variable frequency drive
Although primarily used to improve process control, a variable frequency drive may also be used to reduce the starting current, providing the lowest possible current at the highest possible torque. It provides a performance similar to a soft starter at the startup sequence.

A variable frequency drive is expensive and costs considerably more than a soft starter.



Torque curve at changeover that occurs too early.



Current curve at changeover that occurs too early.

Optimizing the startup sequence

Theoretical analysis

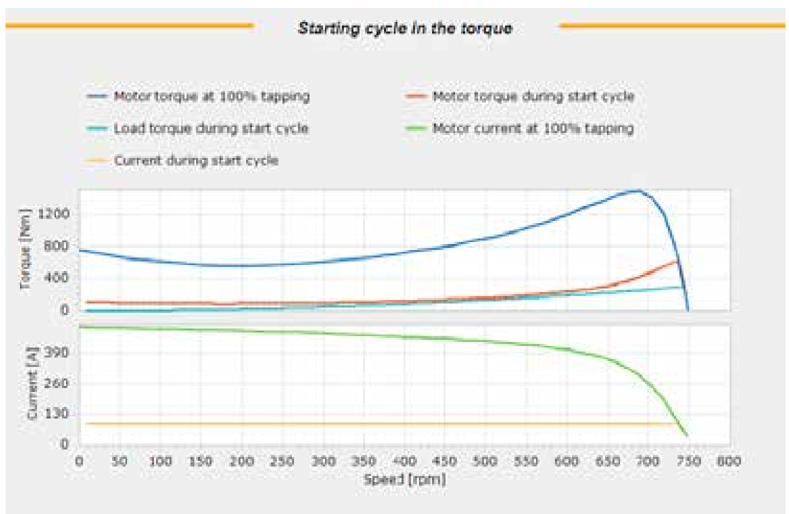
We have extensive experience in conducting theoretical analysis on pump systems using the Flygt Engineering Tool, our specially developed engineering software program. The program has a module dedicated to transient analysis for pump systems and includes a module on dealing with transients at pump startup.

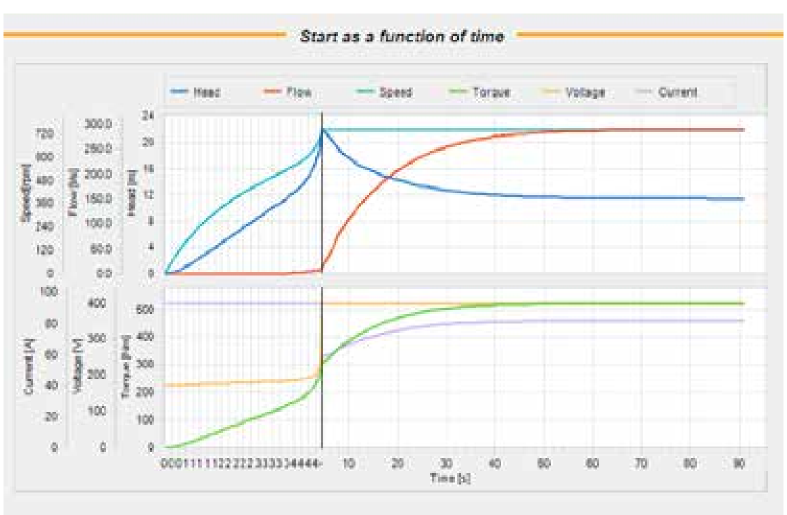
The start analysis module in the software program can calculate the startup sequence for direct-on-line starters as well as for reduced voltage starters, such as star-delta starters, soft starters, and variable frequency drives.

If the tapping is unknown, the Flygt Engineering Tool can calculate and recommend suitable tappings for the selected starting method and indicate the minimum starting current required to achieve optimal performance.

Key features include the ability to account for the acceleration of the water column and the ability to use defined motor characteristics when analyzing the starting process. This yields more accurate results than most methods found in handbooks.

With this information, you can receive an accurate and detailed analysis of pump and system startup with centrifugal and propeller pumps in both filled and empty systems.





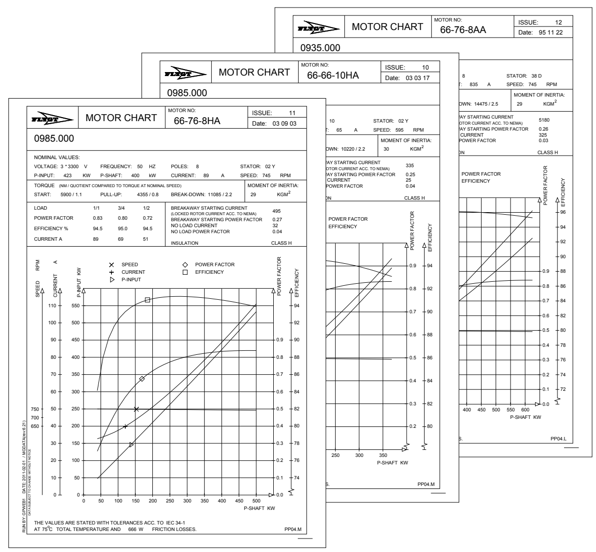
The Flygt Engineering Tool produces various graphs to evaluate and analyze pump and system startup.

Premium products

In order to provide reliable pumps, Flygt both designs and manufactures pump motors, which are designed for powering the hydraulics of a pump unit. Powering a hydraulic part of a pump unit for submersible duty requires a custom motor design. More specifically, cooling of a standard motor is generally handled through the use of fans. A submersible pump motor, on the other hand, is cooled either by the surrounding media or by a cooling jacket with liquid cooling media inside, which in turn exchanges heat with the surrounding media.

Flygt pump motors are designed and manufactured to operate under these conditions in a reliable and effective way. Having complete knowledge of the motor characteristics implies accurate start calculations when determining motor function with all types of starting methods.

Manufacturing of Flygt motors.



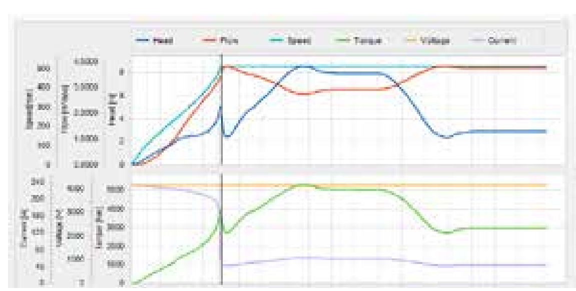
Flygt motor curves.

Proven worldwide

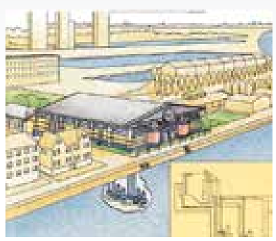
Flygt has designed pump stations and performed start calculations for thousands of installations around the world. Engineering expertise and years of experience have resulted in the success of these installations. Two such installations are described below.

Mexico: Propeller pump stations

Challenge
A major city in Mexico has three different propeller pump stations to handle combined wastewater and stormwater pumping. For nine months of the year, the stations transport wastewater and during the three-month rainy season, a combination of sewage water and stormwater. Backup diesel generators are installed to deliver power during power failures. To dimension the generators, accurate start calculations are essential.



Solution
We recommended the installation of 27 Flygt 7121 propeller pumps for a total capacity of approximately 80 m^3/s (1,268,000 US GPM) at the three stations. To verify that the pumps would have sufficient starting torque and start currents that are not too high, we conducted and analyzed start calculations to ensure that the values for both torque and current were sufficient.



United Kingdom: Sewage and stormwater pump stations

Challenge
The revival of one of Britain's largest commercially unexploited land areas called for multi-phase construction of two large pump stations. One pump station was to provide drainage for a combined flow of sewage and surface water, yet ensure separation of surface water for discharge directly into a nearby river. The other was to provide adequate drainage for stormwater for the continuing redevelopment of the area.

Solution
For the first pump station, Flygt developed a complete mechanical and electrical package that will cost-effectively pump sewage and surface water for the entire redeveloped area. Designed to separate foul and surface water flows into two drainage networks, the system consists of two Flygt CP 3300 drainage pumps and 10 Flygt CP 3500 stormwater pumps in a twin level wet well with siphonic discharge into a surge chamber.

This configuration with its circular sump design provides a total station capacity of 12 m^3/s (190,000 US GPM) at a pump station that is 50% smaller than standard stations. It ensures that surface water can be efficiently and economically discharged directly into the river without overloading the local sewage works. It also drastically reduces construction, installation, operating, and maintenance costs.

For the second pump station, we used a circular design with 18 radially positioned submersible pumps that discharge siphonically into a central chamber above the inlet chamber. Installed inside a wet well 28 m (90 ft) deep are 16 Flygt CP 3311 pumps for handling stormwater and two Flygt CP 3300 drainage pumps. With a total capacity of 8 m^3/s (125,000 US GPM), this station is one of the world's largest using submersible technology.

For both pump station solutions, we conducted and analyzed start calculations to ensure reliable starts, long-lasting equipment, and optimal hydraulic performance.

Engineering & Expertise

To ensure reliable and highly efficient operation, we offer comprehensive support and service for pump station design, system analysis, installation, commissioning, operation, and maintenance.

Design tools

When you design pump stations, we can offer advanced engineering tools to generate sump designs. Our design recommendations give you essential information regarding dimensions and layout. In short, we assist you every step of the way to make sure you optimize performance and achieve energy-efficient operations.

Theoretical analysis

Computational fluid dynamics (CFD) can provide far more detailed information about the flow field in a fraction of the time required to get the same information through physical hydraulic scale model testing. Using CFD in combination with computer-aided design (CAD) tools, it is possible to obtain a more efficient method of numerical simulation for pump station design.

To obtain a reliable, energy-efficient pumping system, it is important to analyze all modes of operation, including the transient effects at pump start and stop with respect to flow and head as well as the electrical parameters such as current and torque. It is also important to have an accurate mathematical description of the pump and motor, which is gained, in part, from extensive testing in our laboratories.

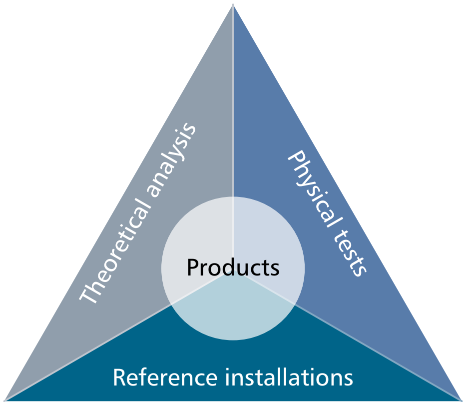
Physical testing

Physical hydraulic scale model testing can provide reliable, cost-effective solutions to complex hydraulic problems. This is particularly true for pump stations in which the geometry departs from recommended standards or where no prior experience with the application exists. Scale model testing can also be employed to identify solutions for existing installations and has proven to be a far less expensive way to determine the viability of possible solutions than through trial and error at full scale.

When our standard design recommendations are not met, we can assist in determining the need for physical testing as well as planning and arranging the testing and evaluating the results.

Reference installations

We have conducted system analysis and designed pump stations for thousands of installations around the world. Engineering expertise and years of experience gained from the design and operation of these installations have been a critical success factor when analyzing, testing, and commissioning new pump installations.



Engineering & Expertise

Model test photos courtesy of Hydrotec Consultants Ltd.

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1) The tissue in plants that brings water upward from the roots;
2) a leading global water technology company.

We're 12,000 people unified in a common purpose: creating innovative solutions to meet our world's water needs. Developing new technologies that will improve the way water is used, conserved, and re-used in the future is central to our work. We move, treat, analyze, and return water to the environment, and we help people use water efficiently, in their homes, buildings, factories and farms. In more than 150 countries, we have strong, long-standing relationships with customers who know us for our powerful combination of leading product brands and applications expertise, backed by a legacy of innovation.

For more information on how Xylem can help you, go to **www.xyleminc.com**

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