Part I

Dry-Running Protection of Centrifugal Pumps in Ex-Atmospheres

Benefits of Active Power Monitoring with SIMOCODE pro

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Contents

Part I

Features of the protection method and implementation into the SIMOCODE motor control device

Abstract

Dry-running protection is mandatory for safe operation of centrifugal pumps, which are used for conveying flammable fluids and/or are installed in potentially explosive atmospheres.

While pump manufacturers must perform an ignition hazard assessment, project engineers have to identify the adequate protection method in co-operation with plant operators, who have to integrate it into their explosion protection concept and bear the responsibility for safe operation.

One possible indirect method for dry-running protection is monitoring of the active power and switching off the motor and thus the pump when a certain active power level is undercut (indication for dry-running). This can be realized with the SIMOCODE pro motor control device, which provides the dry-running protection function, but itself is installed in a switchboard outside of potentially explosive atmospheres. The method is especially suited for centrifugal pumps with radial impellers, which are operated continuously. Main advantages of this indirect "software" solution are the adjustability of the trip value, the applicability to all media (regardless of their characteristics, e.g. corrosivity) and the absence of inline sensors (allowing simple retrofit solutions).

With active power monitoring, explosion protection is provided by control of ignition sources at the pump. The safety device fulfills the requirements of SIL 1 according to the classification of IEC 61508. The conformity assessment has been executed by employing the international standards ISO 80079-36 and ISO 80079-37. For the respective SIMOCODE hardware components, an EU-Type Examination Certificate for dry-running protection of centrifugal pumps based on 2014/34/EU (ATEX) and an IECEx Certificate of Conformity (CoC) are available, thus enabling world-wide application.

In addition to pump protection, the installed SIMOCODE pro components also serve as ATEX-certified overload and thermistor protection device for explosion-proof motors.

This paper as **Part I** (of 2) describes the basics for the application of active power monitoring with SIMOCODE pro as protection technique, including the required monitoring parameters and the determination of the active power trip level by a so-called Teach-in procedure. Besides that, the functionality and the interaction of SIMOCODE components for ATEX-approved dry-running protection of pumps are characterized, together with elementary statements on the possibility of simultaneous ATEX-approved motor protection.

The separate paper on **Part II** outlines the test trials, which were conducted in the course of the development of the method in order to proof its effectiveness. Furthermore, the field of directives and standards is highlighted by explaining the Ex-markings of the SIMOCODE devices and the resulting use cases for Ex-protection as well as possible contributions of the method to an ignition hazard assessment (to be compiled by the pump manufacturer) and to an explosion protection concept (to be compiled by the plant operator).

1 Introduction

Due to their robust and unpretentious construction features, centrifugal pumps are and will be widely used in production plants within the process industries for conveying liquid fluids. For the overwhelming part of the applications they are combined with an electrical motor driven by 3-phase alternating current (AC). Dry-running of centrifugal pumps immediately poses serious threats. A material damage of the pump (starting with the sealing) is likely to happen after a very short time period due to the missing lubrification effect of the liquid.

In case the conveyed liquid is flammable, an explosive atmosphere can be built up inside the pump by the gas/vapor phase together with oxygen (e.g. from air ingress) under dry-running conditions. Simultaneously, the appearance of an ignition source (e.g. hot surface or mechanical spark) inside the pump can occur, which together would most likely lead to an explosion.

Hot surfaces also constitute potential ignition sources at the outer surface of the pump. [8] Explosion risks outside of the pump can be enhanced by the emission of flammable substances from the pump due to the material damage.

Considering all this, dry-running of centrifugal pumps must be prevented by all means whenever flammable substances can be present inside the pump or outside in the vicinity of the pump. Therefore, effective and reliable monitoring has to be applied, which will initiate a shut-down of the motor and thus of the pump in case of violation of appropriate limits.

2 Methods for dry-running protection of centrifugal pumps

2.1 Conventional methods employing additional sensors

Several conventional methods for dry-running protection of pumps are applied in the different branches of process industries (e.g. chemical industry). They are all sensor-based, requiring costs for hardware, installation and maintenance and making their functionality depending on the location of the installation and on potential risks of fouling and corrosion.

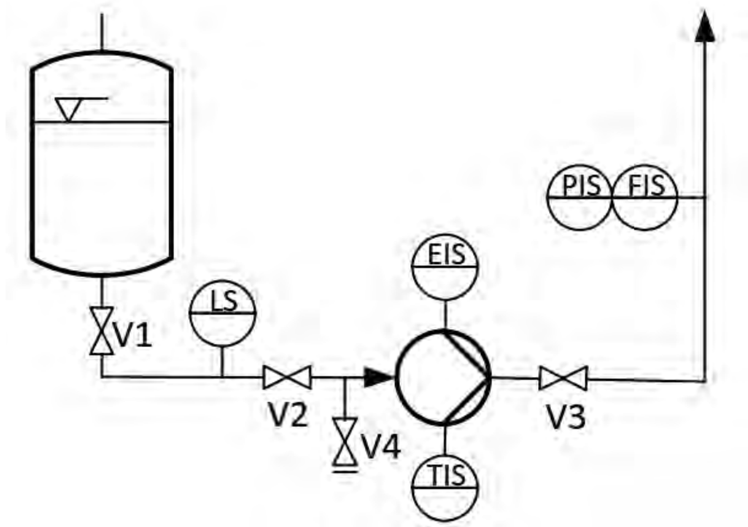

Fig. 2.1: conventional sensors for dry-running protection of pumps

Choice of the sensor (or of a combination) has in the end to be performed by the plant operator (usually assisted by the project engineer) and is depending on the specific requirements for protection. The most common sensors and their characteristics are (see Fig. 2.1):

- level switch LS (suction side): widely used in process industries, under the precondition that fouling and corrosion can be controlled. However, level switches might give false alarm when gas or vapor bubbles or vibrations of the pipeline occur. Furthermore, no trip level can be set – there is only a digital signal 0 or 1. In case valve V2 is closed by mistake, dry-running of the pump will not be detected. In case valve V3 is closed by mistake or the line is blocked on the discharge side, "internal" pump operation at zero external flow and potential overheating will also not be detected.
- flow sensor/switch FIS (discharge side): gives a direct indication of the flow rate. However, the location and especially sufficient lengths of inlet and outlet paths are critical. During operation, delay periods as well as potential false alarms by solid particles have to be considered.
- pressure sensor/switch PIS (discharge side): both zero flow (low pressure) and zero external flow (with blocking downstream of sensor - high pressure) will be detected. The system, however, is very sensitive towards blocking of the measuring tube and false alarm by gas or vapor bubbles or vibrations.
- temperature sensor/switch TIS: gives a direct indication for potential ignition source "hot surface". The correct location of the sensor (usually directly at the surface of the pump or in the close vicinity) is decisive. Delay periods caused by the procedure of heat conduction and by the sensor itself have to be considered.

All the conventional methods have in common that they employ an additional sensor, thus dry-running protection is realized as a functional chain (sensor – control unit – motor feeder, see Fig. 2.2) of devices from different suppliers. For use in hazardous areas, proof of correct interaction and of compliance with SIL (safety integrity level) requirements (as defined in IEC 61508 [1]) has to be individually executed by the plant operator.

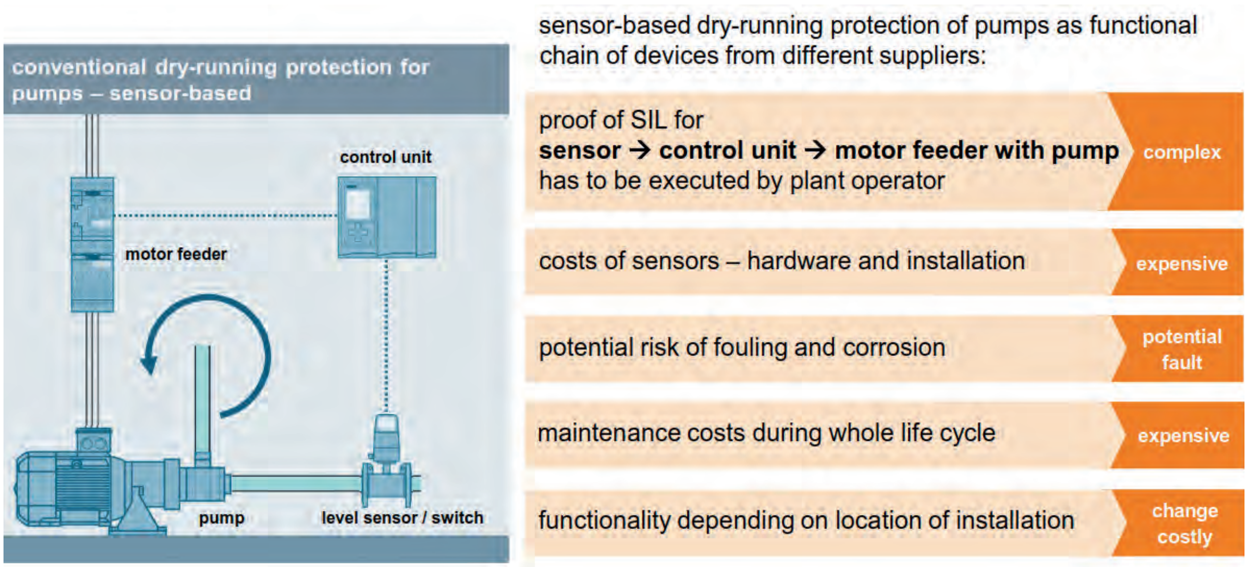

Fig. 2.2: Functional chain of conventional methods for dry-running protection

2.2 Active power monitoring with SIMOCODE pro V using motor data (without extra sensor)

Another very effective measure for dry-running protection is monitoring of the active power required by the motor, e.g. with the help of the motor control device SIMOCODE pro V. For centrifugal pumps with radial impellers (as applied in the very most cases) there is a clear, progressive dependence of the active power and the flow rate – the higher the flow rate, the higher the active power (see Fig. 2.3). Thus, if the active power value falls below a defined minimum value, this means an indication for dry-running conditions, and the motor is switched off by the control device. Depending on the requirements of the explosion protection concept (see [11] for the necessity of this document) of the plant operator, the use of active power monitoring for dry-running protection is conceivable as a stand-alone solution, or in combination with other monitoring devices, e.g. one of the aforementioned measures.

With active power monitoring, the critical state of "internal" pump operation (closed valve or blockade on discharge side) at zero external flow (danger of overheating with potential ignition source "hot surface") will be reliably detected. Gas bubbles, which might contain oxygen from air ingress, will lead to a considerable drop in active power and thus to a fast shutdown, whereas vapor bubbles caused by cavitation on the suction side will to a certain extent collapse due to pressure increase in the pump and will only be of remarkable impact on the active power in case of unwanted strong cavitation.

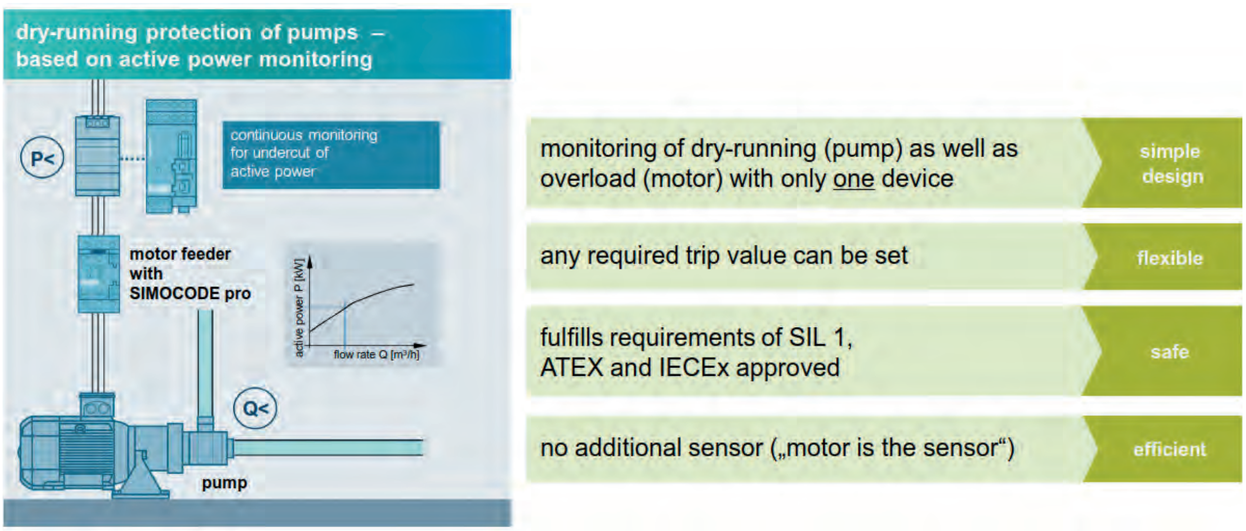

Fig. 2.3: Functional chain of active power monitoring (undercut of defined minimum value) for dry-running protection

SIMOCODE pro V fulfills the requirements of SIL 1 following the classification of IEC 61508 [1] (see certificate [2]) for dry-running protection and is approved for applications according to ATEX [3] and IECEx [4]. No additional hardware devices have to be installed for the dry-running protection function of SIMOCODE pro V, the motor acts as a sensor. However, attention has to be drawn to the definition of the values of the monitoring parameters to be set in SIMOCODE pro V, especially to the determination of the adequate and required active power trip level.

As a further benefit, the SIMOCODE components used for dry-running protection can simultaneously maintain the motor protection, for which an ATEX-certification is also available [5].

3 Description of active power monitoring as protection technique

3.1 Operating range of centrifugal pumps – pump shaft power P_P vs. flow rate Q

Pump manufacturers provide pump characteristic curves (usually simply called "characteristics"), which are valid for a specific constructive set-up (e.g. impeller diameter) and feature the pump shaft power PP vs. the flow rate Q (see Fig. 3.1). These characteristics depend on the property data of the medium (mainly density and viscosity), which themselves depend on the process conditions (mainly temperature). Thus, in catalogues characteristics are usually given for water at ambient temperature, whereas specific characteristics (for the medium conveyed at process conditions) are enclosed when pumps are sold and delivered for the respective use case. The pump shaft power is deducted from the torque measured at the pump shaft. Catalogue curves of the pump shaft power given by most of the pump manufacturers usually include: hydraulics (conveying the fluid), frictions of ball bearings (grease) of the pump, frictions of a basic sealing system (single-acting mechanical seal or Foucalt currents for magnetic coupling).

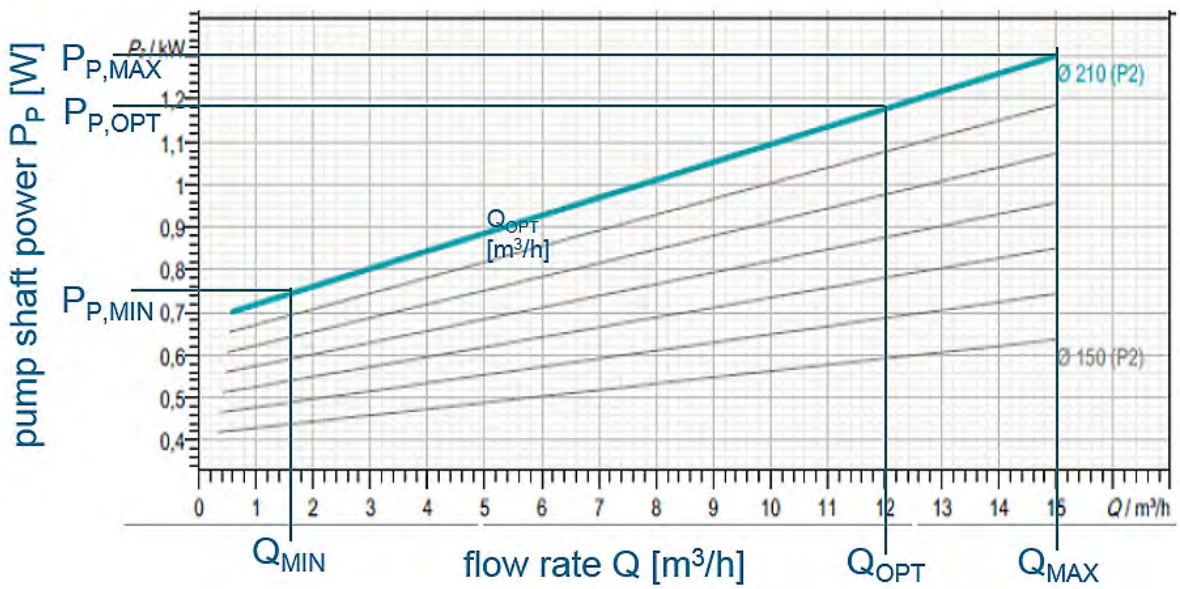

Fig. 3.1: pump characteristic – pump shaft power P_P vs. flow rate Q

Pumps shall preferentially be run at the operating point, represented by the optimum flow rate Q_{OPT} and corresponding shaft power $P_{P,OPT}$. The operating range is between the minimum allowable flow rate Q_{MIN} (shaft power $P_{P,MIN}$) and the maximum allowable flow rate Q_{MAX} (shaft power $P_{P,MAX}$). Most of the pump manufacturers understand Q_{MIN} as the value which should not even be undercut in short-term operation and pose a limit of e.g. $Q > 1.2 \times Q_{MIN}$ for long-term operation for reasons of deterioration. Thus, flow rate values of $Q < Q_{MIN}$ shall be prevented by monitoring devices, e.g. active power monitoring with SIMOCODE pro V.

[It should be noted that exceeding the maximum flow rate will eventually lead to motor overload; this can also be monitored with SIMOCODE pro V – see Section 4.2.]

3.2 Evaluation of active power P vs. pump shaft power P_P – no mathematical relationship

In practical use, the pump shaft power PP cannot be monitored – but rather the motor active power P is the significant parameter. For quantification of the motor active power consumption, the combination of pump + coupling + motor has to be considered, and there are numerous influencing factors such as (see Fig. 3.2):

- variations in physical property data of the medium (e.g. density, viscosity, solid particles, gas bubbles)
- fluctuations in process / environmental conditions (e.g. temperature)
- frictions of the bearings of motor and pump
- losses of the seal and of the coupling
- efficiency losses of the motor (depending on the load range)

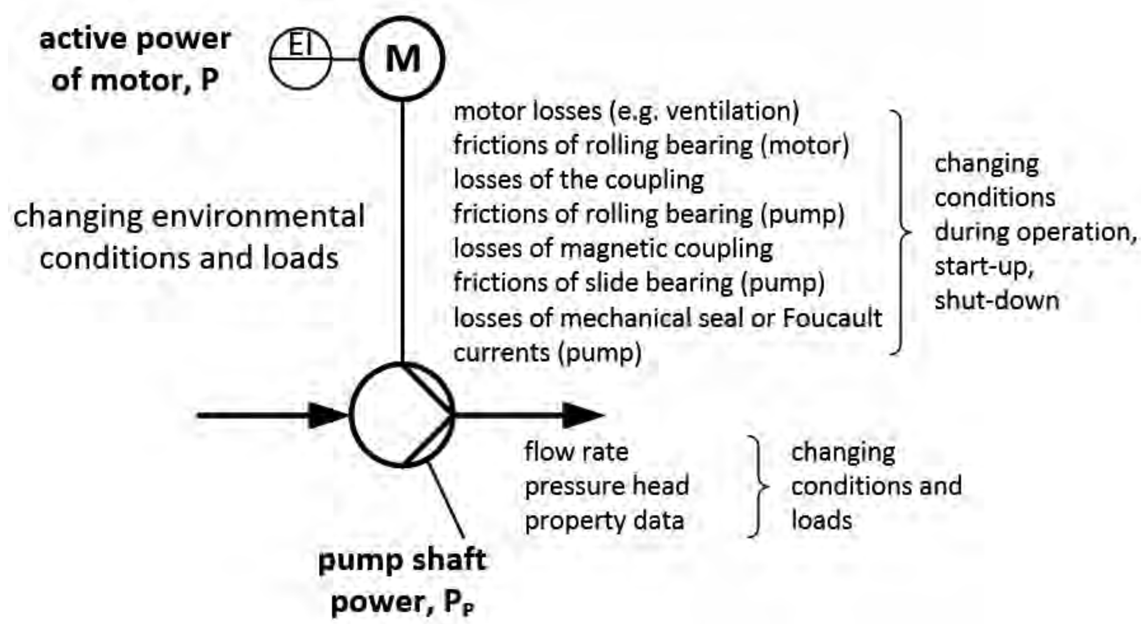

Fig. 3.2: factors influencing the motor active power P and interrelation with the pump shaft power P_P

A practical example for the difference between pump shaft power and motor active power is shown in Fig. 3.3 for a set-up (for demonstration purposes) consisting of:

- KSB Etabloc ETB 040-025-160 - centrifugal pump with radial impeller (Ø 135 mm) and single-acting mechanical seal
- electrical motor Siemens 90L with nominal power P_N = 2.2 kW

The curve for pump shaft power P_P vs. flow rate Q was taken from the documentation provided by the pump manufacturer KSB, whereas data for active power P were measured with SIMOCODE pro. In many cases, the curves can be approximated by a straight line (within a certain range), but they are usually not parallel. Within the curves, Q = 0 does not mean dry-running, but rather "internal" pump operation (closed valve on discharge side) with zero external flow. It must be noted that the centrifugal pump in this demonstrator set-up features an impeller with reduced diameter (135 mm vs. usually 169 mm) in order to limit the flow. Thus, the efficiency factor of this particular pump is smaller than usual.

The single data point $P_{0,dry}$ (Q = 0) = 314 W was obtained by manually emptying the pump by opening a respective valve and then starting the pump – this is the condition which has to be prevented in practical operation by all means.

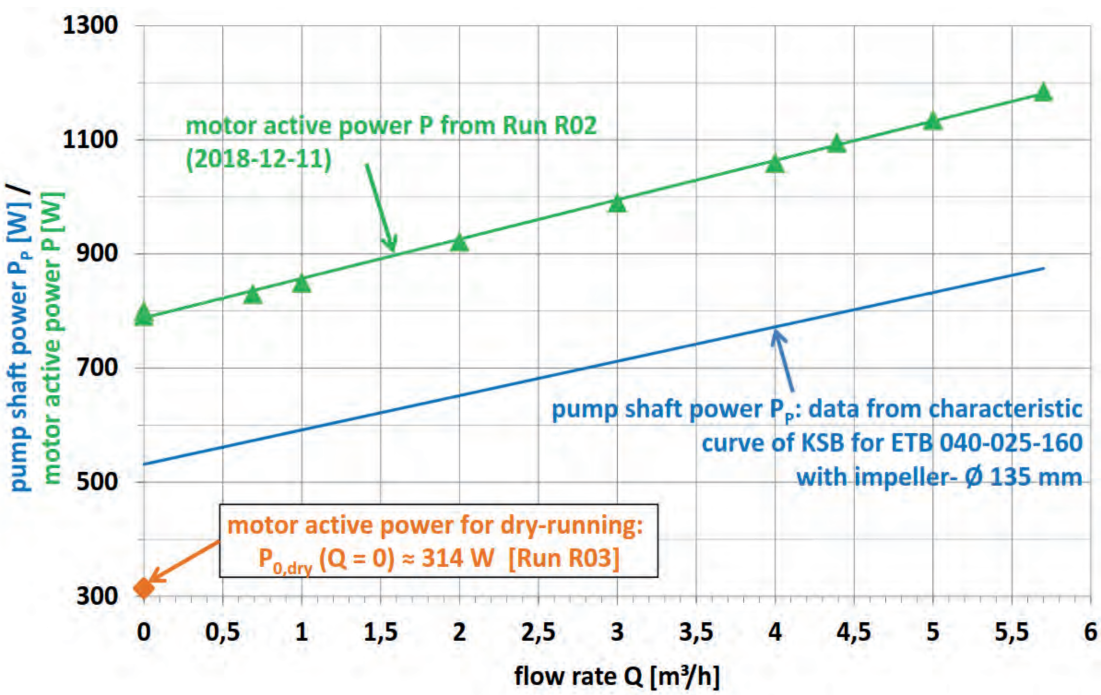

Fig. 3.3: pump shaft power P_P and motor active power P vs. flow rate Q for KSB Etabloc ETB 040-025-160 (impeller- Ø 135 mm – customized for demonstrator set-up and smaller than usual, thus lower efficiency factor) and motor Siemens 90L 2.2 kW, 2900 rpm; source: KSB individual pump data sheet for pump shaft power, other data Siemens trials, November 2018

Distinctive data are listed in Table 3.1. As specified by the manufacturer, the minimum flow rate $Q_{MIN} = 0.69\ m^3/h$ should not be undercut during pump operation.

flow rate	pump shaft power	motor active power
$Q_{OPT} = 4.39\ m^3/h$	$P_{P,OPT} = 800\ W$	$P_{OPT} = 1095\ W$
$Q_{MIN} = 0.69\ m^3/h$	$P_{P,MIN} = 575\ W$	$P_{MIN} = 830\ W$
Q = 0 ("internal" pump operation)	$P_{P,0} = 530\ W$	$P_0 = 796\ W$
Q = 0 (dry)	(no data)	$P_{0,dry} = 314\ W$

Table 3.1: data for pump shaft power and active power for KSB Etabloc ETB 040-025-160 (impeller- Ø 135 mm) and motor Siemens 90L 2.2 kW; source: Siemens trials, November 2018

Due to the interaction of all the factors listed, there is no simple mathematical relation between active power P, pump shaft power P_P and flow rate Q, which would enable deduction of the required active power trip value P_{TRIP} from P_P and Q for all arrangements and applications. However, P_{TRIP} can be easily determined by means of a so-called Teach-in procedure, which is performed under real process conditions. Prior to description of the Teach-in, it is beneficial to have a closer look at the necessary set of parameters, which have to be defined for the active power monitoring function in SIMOCODE pro.

3.3 Parameters for active power monitoring – P_{TRIP}, $t_{V,TRIP}$ and t_{BRIDGE}

The relevance of the parameters, which have to be defined by the operator and implemented into the SIMOCODE pro parameter settings for dry-running protection with active power monitoring, is illustrated in Fig. 3.4 by displaying the active power vs. time. The peak heights and lengths in the diagram are just for demonstration purposes (no scaling of the axes).

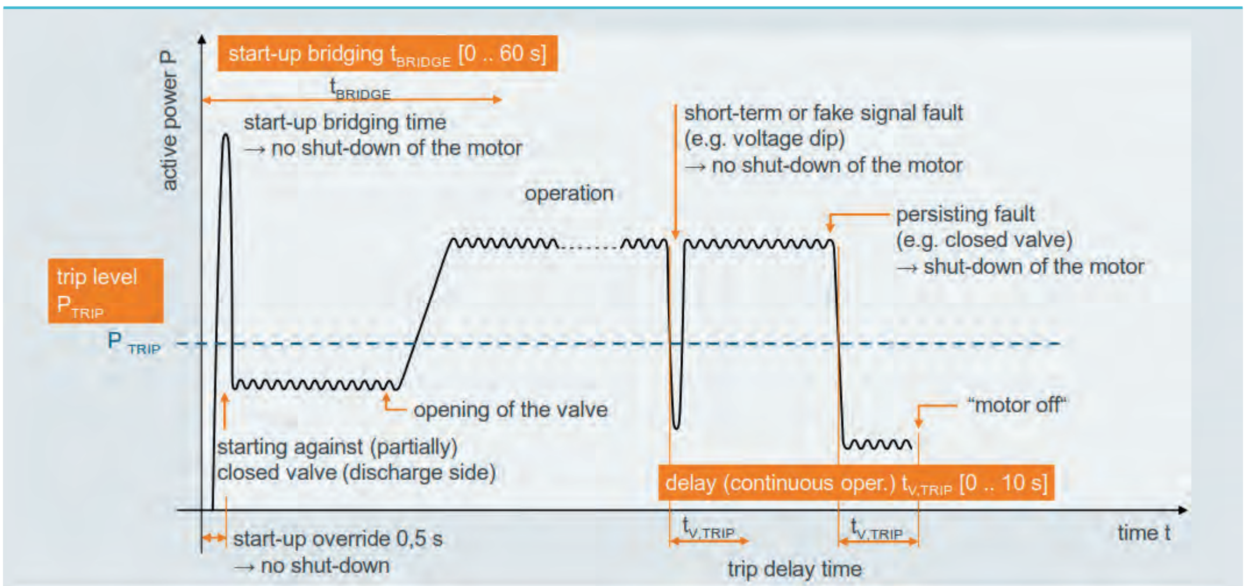

Fig. 3.4: relevance of parameters for dry-running protection by active power monitoring [6]

The respective parameters are:

- **Trip level P_{TRIP} of active power** (specification will be explained in the following sections).
- **Trip delay time $t_{V,TRIP}$ during continuous operation** of the pump: in order to prevent unnecessary shut-downs caused by short-term or fake signals, a persisting undercut of active power must prevail during $t_{V,TRIP}$ before a trip is initiated. The parameter value must be short enough to ensure safe functioning of the dry-running protection, but long enough to ensure safe operation of the pump. Thus a set-up range of 0 ... 10 s is pre-defined, and the default value is set to 0.5 s.
- **Start-up bridging time t_{BRIDGE}:** temporary suppression of trip to prevent an unintended trip (due to undercut of active power trip level) when starting the pump with a (partly) closed valve on the discharge side, which is common practice in process industries. The parameter value must be long enough to enable start-up of the pump, but short enough to ensure safe functioning of the dry-running protection. Thus a set-up range of 0 ... 60 s (to encompass pumps of all sizes) is pre-defined. The default value is set to 0 s, so that the operator must actively define an appropriate parameter value for cases when the pump is started with a (partly) closed valve on the discharge side. Precondition for safe start-up is prior liquid filling of the pump (organizational measure, as instructed by the pump manufacturer in his manual).

Immediately after starting the motor, inrush effects (< 1 s) will occur with extensive fluctuations of the active power. In order to prevent undesired system responses, a start-up override of 0.5 s is unchangeably fixed in the SIMOCODE firmware, during which trip activation is suppressed. Start-up override and start-up bridging time t_{BRIDGE} start in parallel at t = 0, whereas t_{BRIDGE} and $t_{V,TRIP}$ are consecutive.

Examples (for permanent undercut of P_{TRIP}):

$t_{BRIDGE} = 10$ s	$t_{V,TRIP} = 2$ s	➔	motor off" at t = 12 s
$t_{BRIDGE} = 0$ s	$t_{V,TRIP} = 2$ s	➔	motor off" at t = 2 s
$t_{BRIDGE} = 0$ s	$t_{V,TRIP} = 0$ s	➔	motor off" at t = 0,5 s

After a trip has been initiated, automatic re-starting of the drive motor is not possible. The motor must be manually re-started, upon having identified the reason for the trip and corrected it, if necessary.

3.4 Recommendation: active power trip value 10 % higher than value at minimum flow rate

The following considerations have been made for specification of an appropriate trip level of active power P_{TRIP}:

- Pump operation should not take place below the minimum flow rate Q_{MIN}; an undercut of Q_{MIN} is an indication for upcoming dry-running.
- Uncertainties are incorporated into all data which are measured and processed (worst case for determination of active power with SIMOCODE pro: max. ± 5 % for actual measurement and max. ± 5 % for long-term drift).
- The reasonable operating range of the pump should not be curtailed too much by a trip level set too high.

Thus the following value is specified: $P_{TRIP} = 1.1 \times P_{MIN}$

applied to example listed in Table 3.1: $P_{TRIP} = 1.1 \times 830\ W = 913\ W$ (see Fig. 3.6)

This means that the active power trip level is 10 % higher than the active power corresponding to the minimum flow rate Q_{MIN}. For the aspect of explosion protection, it is important to note that operation at Q_{MIN} does not yet mean the dangerous condition of dry-running at Q = 0, therefore the specified value is on the safe side and only a recommendation for the plant operator, who bears the responsibility and can set any appropriate level matching his operational and safety needs.

3.5 Precondition: minimum difference of 20 % between active power at minimum and optimum flow rate

Operability is the main criterion for defining the requirements for the progressiveness of the curve of active power P vs. flow rate Q. In order to be able to both reliably detect the trip level value and permanently run the pump at the operating point without unwanted trips caused by temporary fluctuations of the flow rate - and considering the uncertainties in data processing mentioned in Section 3.4, the active power P_{MIN} at minimum flow rate Q_{MIN} must be at least 20 % below the value P_{OPT} at the operating flow rate Q_{OPT}.

Thus the following limit is specified: $P_{MIN} / P_{OPT} < 0.80$

applied to example listed in Table 3.1: $P_{MIN} / P_{OPT} = 830\ W / 1095\ W = 0.76 < 0.80$

[pump shaft power for comparison: $P_{P,MIN} / P_{P,OPT} = 575\ W / 800\ W = 0.72$*]*

It is important to note that the active power ratio P_{MIN} / P_{OPT} depends on the combination of pump and motor. In the project planning phase, however, only characteristics of pump shaft power P_P vs. flow rate Q are available from the pump manufacturer. The pump shaft power ratio $P_{P,MIN} / P_{P,OPT}$ is similar to the active power ratio and thus can be taken as criterion for fulfillment of the requirement $P_{MIN} / P_{OPT} < 0.80$, as long as the motor matches the pump. Choosing the correct motor size is therefore essential, since extreme oversizing of the motor (and consecutive unfavorable part-load operation) promotes high values of P_{MIN} / P_{OPT}. For the test case the motor 2.2 kW matched the pump KSB Etabloc ETB 040-025-160, as expressed by the similar value for active power (0.76) and pump shaft power (0.72) ratio. The relatively high value of $P_{MIN} / P_{OPT} = 0.76$ is inherent (e.g. due to small pump with small impeller diameter), but unusual. According to a thorough analysis of nearly 300 manufacturers' characteristics, more than 85 % of centrifugal pumps commonly used in process industries feature a ratio of pump shaft power (as indication for active power ratio) well below 0.65. But even at the challenging test condition with a value of $P_{MIN} / P_{OPT} = 0.76$ near the limit, operability of the pump as well as monitoring of P_{TRIP} was maintained without restrictions during the tests.

3.6 Teach-in for determination of active power trip value and for parameter input

Due to the fact, that the curve for active power P vs. flow rate Q and thus the active power trip value P_{TRIP} cannot be deducted mathematically, it is recommended to determine P_{TRIP} with the help of a so-called Teach-in, which is performed with the pump installed in the production plant and process media under operation conditions and thus incorporates all influences from the process and from all pieces of equipment. Precondition is the availability of a flow measurement. Execution of the Teach-in will require approximately 10–15 min, when the plant is running at operating conditions.

The Teach-in is started from the Engineering Software SIMOCODE ES, which can be accessed from the TIA (Totally Integrated Automation) portal framework and consists of 6 steps of a so-called Teach-in Wizard (assistant with dialogue windows). These are (see Fig. 3.5):

1. Start – pump must run with operating conditions, especially temperature
2. Adjust optimal flow rate Q_{OPT} at plant ➔ obtain active power value P_{OPT}
3. Adjust minimum flow rate Q_{MIN} at plant ➔ obtain active power value P_{MIN}
4. SIMOCODE-internal check for $P_{MIN} / P_{OPT} < 0.80$;
   if check is passed, then automatic setting of $P_{TRIP} = 1.1 \times P_{MIN}$
5. Enter parameter values for delay time $t_{V,TRIP}$ at continuous operation and for start-up bridging time t_{BRIDGE} (values have to be defined by the plant operator)
6. Finish – activation of protection function

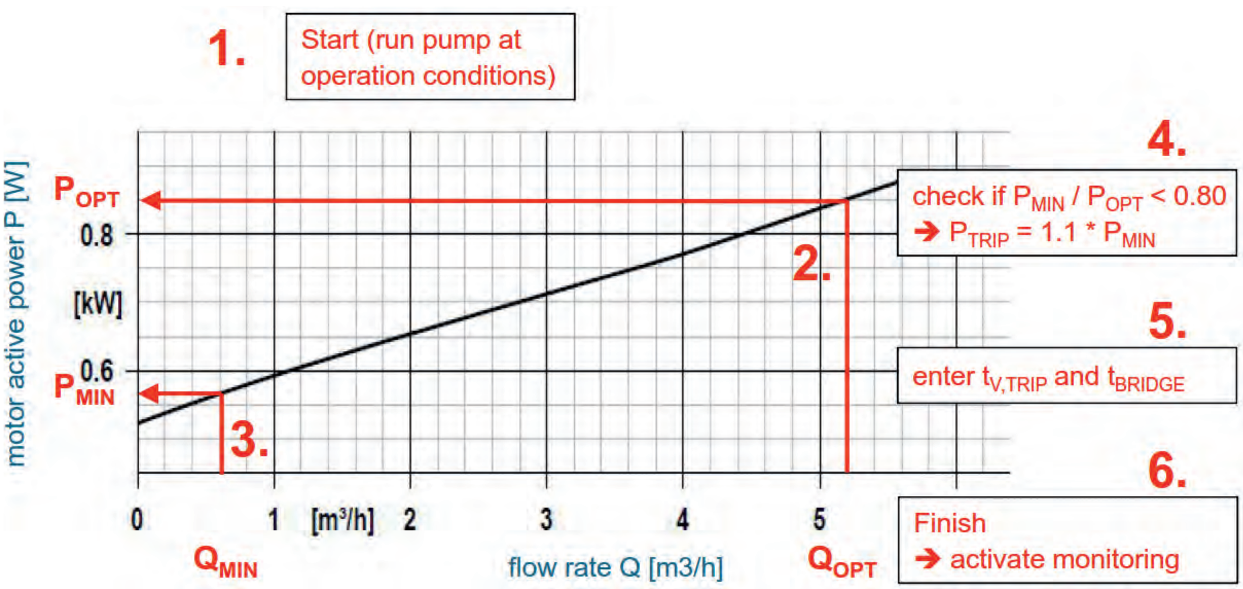

Fig. 3.5: Illustration of the Teach-in steps in a diagram of active power P vs. flow rate Q

3.7 Plant protection during Teach-in

Explosion protection of the pump has to be facilitated also during the Teach-in procedure, but only basic protection with an active power temporary trip level $P_{TRIP,TEMP} < P_{MIN}$ can be employed, because otherwise unwanted shut-downs might occur when setting the minimum flow rate Q_{MIN}. In case no other information is available, it is recommended to set the temporary trip level of the active power 30 % above the pump shaft power $P_{P,0}$ at Q = 0 ("internal" pump operation).

Thus the following value is specified: $P_{TRIP,TEMP} = 1.3 \times P_{P,0}$

applied to example listed in Table 3.1: $P_{TRIP,TEMP} = 1.3 \times 530\ W = 689\ W$ (see Fig. 3.6)

The reasonability of this setting has been verified for various pump types from different manufacturers. The value is high enough to protect against dry-running (for the example case: $P_{TRIP,TEMP}$ = 689 W vs. $P_{0,dry}$ = 314 W), but low enough to enable execution of the Teach-in without unplanned interruption (for the example case: $P_{TRIP,TEMP}$ = 689 W vs. P_{MIN} = 830 W).

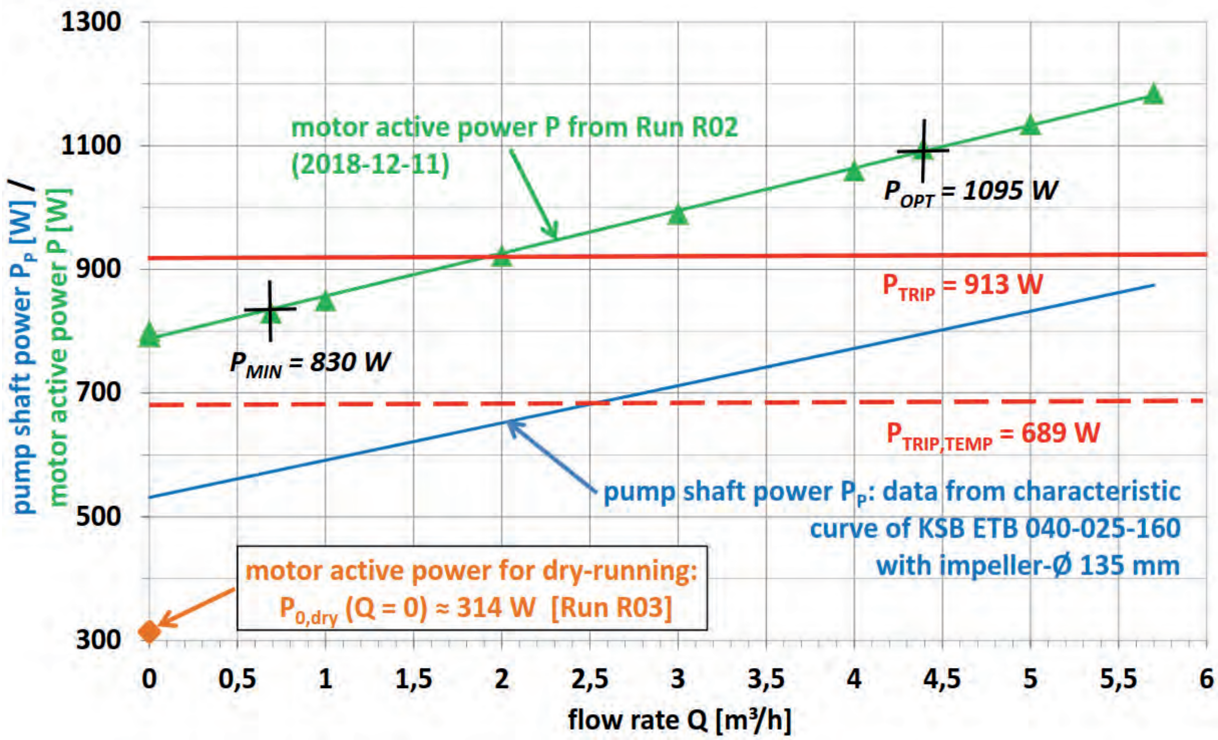

Fig. 3.6: active power trip level $P_{TRIP} = 1.1 \times P_{MIN}$ and active power temporary trip level $P_{TRIP,TEMP} < P_{MIN}$ for KSB Etabloc ETB 040-025-160 (impeller- Ø 135 mm – customized for demonstrator set-up and smaller than usual, thus lower efficiency factor) and motor Siemens 90L 2.2 kW, 2900 rpm;
source: KSB individual pump data sheet for pump shaft power, other data Siemens trials, November 2018

In order to prevent undefined plant conditions in case of unplanned prolongation of the Teach-in, a timer for monitoring of inactivity is started with each opening of a dialogue window within the Teach-in sequence. The timer will shut down the motor and thus the centrifugal pump after a period of 10 min, if the system has permanently remained at the respective dialogue window. However, the timer appears in the dialogue window and can anytime be manually reset to 10 min, in case the operator needs more time.

3.8 Constant monitoring of current and voltage range and asymmetry

For detection of potential hardware defects, the values of current and voltage measured at all three phases are constantly and cyclic (every 100 ms) monitoring with respect to range and asymmetry as long as the dry-running protection function is active.

- monitoring of current
  $I_U < I < I_O$ with I_U lower and I_O upper value. If a violation of the limits or an asymmetry between two phases of ≥ 30 % persists for longer than 5 s, the motor will be shut down.
- monitoring of voltage
  93 V (110 V – 15 %) < U < 794 V (690 V + 15 %). If a violation of the limits or an asymmetry between two phases of ≥ 30 % persists for longer than 5 s, the motor will be shut down.

3.9 Alternative method for parameter input: Engineering Software SIMOCODE ES

As an alternative to the Teach-in sequence, the parameter values for P_{TRIP}, $t_{V,TRIP}$ and t_{BRIDGE} can be directly entered into the SIMOCODE parameter settings with the help of the Engineering Software SIMOCODE ES (see Fig. 3.7). Permission shall be limited to authorized persons. This procedure could be appropriate e.g. for the following cases:

- the plant operator has good knowledge of the pump performance, especially the acceptable active power values
- the plant operator wants to set a higher value of the active power trip level than determined by Teach-in, meaning $P_{TRIP} > 1.1 \times P_{MIN}$

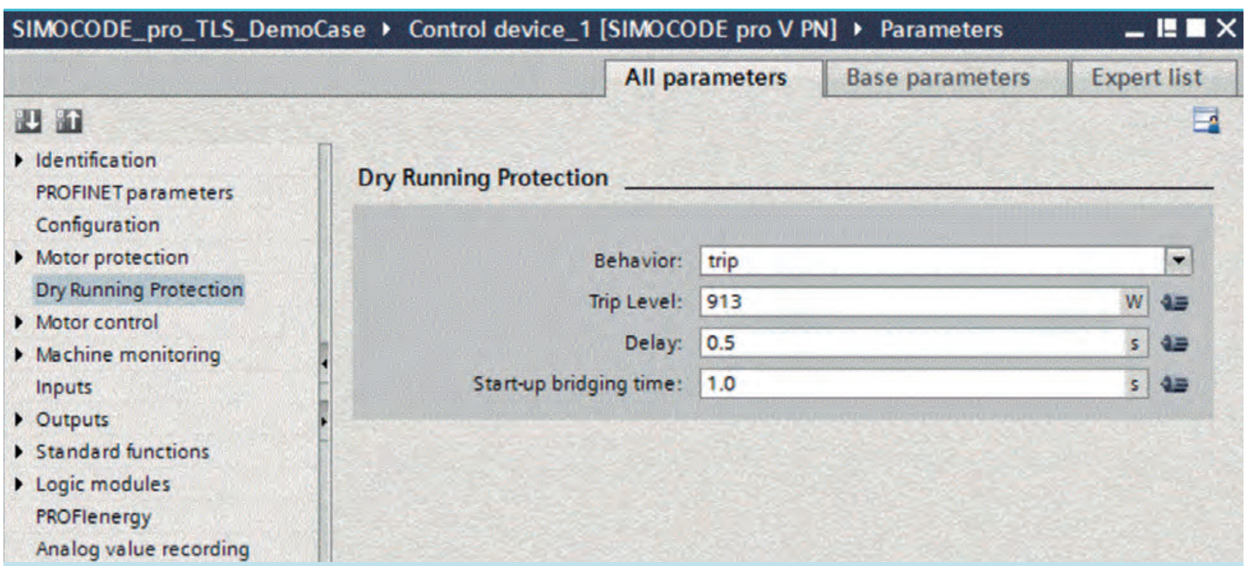

Fig. 3.7: Dialogue window within the Engineering Software SIMOCODE ES of the TIA portal framework for direct input of parameter values for the dry-running protection function

3.10 Records of parameter settings

The defined parameter values, the input method (Teach-in or direct input via Engineering Software SIMOCODE ES) and the time-stamp of the input can be recorded by writing them into an output file (e.g. as PDF or as hardcopy – see Fig. 3.8). It is recommended to do so every time after the parameters have been changed, in order to meet organizational requirements of the Ex-protection concept.

Parameter input by execution of Teach-in:

Dry Running Protection					
Dry-Running Teach-in completed successfully	yes	**Last successful Teach-in**	14.03.2019 17:35:34	**Behavior**	trip
Trip Level	131W	**Active Power Popt**	208W	**Flow Qopt (m³/h)**	4.4
Active Power Pmin	119W	**Flow Qmin (m³/h)**	1.9	**Delay**	0.5s
Start-up bridging time	1.0s				

Direct parameter input by Engineering Software SIMOCODE ES:

Dry Running Protection					
Parameters entered manually	yes	**Behavior**	trip	**Trip Level**	150W
Delay	0.5s	**Start-up bridging time**	1.0s		

Fig. 3.8: Parameter recording for the cases of Teach-in and of direct parameter input with the help of the Engineering Software SIMOCODE ES

3.11 Review of the active power trip value setting and periodic tests

If it is likely that the behavior of the system with respect to the interrelation between active power P and flow rate Q has changed (after significant modifications of the operating conditions or the unit, e.g. after maintenance activities), it is necessary to repeat the Teach-in and thus re-check the parameter value of P_{TRIP}.

Besides that, periodic system tests are required in intervals given by the authorities (e.g. for Ex-protected equipment), at least every 3 years (see IEC 60079-17 [13]). General SIMOCODE system tests can be conducted quite easily with the help of test buttons and LED indicators [6]. Specific system tests with operating medium under operating conditions can partly be deducted from Teach-in results, require approximately 10–15 min and comprise:

- check of potential changes in plant hardware conditions: set the same operating conditions (e.g. medium, temperature, flow rate) as for a previous test, measure at least two values of the active power (e.g. P_{MIN} and P_{OPT}) and compare the values with those from previous tests.
- check of effectiveness of shut-down:
  - Start the pump with targeted flow rate Q_{OPT} and with start-up bridging time $t_{BRIDGE} = 0$ and delay time $t_{V,TRIP} = 0$ and check for immediate shut-down.
  - Start the pump with targeted flow rate Q_{OPT} and with start-up bridging time $t_{BRIDGE} > 0$ and delay time $t_{V,TRIP} > 0$. Reduce flow rate Q and thus active power P incrementally and check for correct shut-down after P_{TRIP} has been undercut and delay time $t_{V,TRIP}$ has elapsed.

4 SIMOCODE components for ATEX-approved dry-running protection of pumps and simultaneous motor protection

With the help of SIMOCODE pro V, the combination of centrifugal pump and motor can be simultaneously protected against extreme conditions on two sides – pump dry-running and motor overload. Both protection functions are ATEX-approved.

4.1 Interaction of Basic Unit and Current-/Voltage Measuring Module for dry-running protection

The protection function “Dry-running protection for centrifugal pumps” is facilitated with the help of two SIMOCODE pro V hardware components (see Fig. 4.1):

- **Basic Unit:** the dry-running protection function is integrated into the firmware of all Basic Units for communication via Profinet, Profibus and EtherNet/IP (starting from a distinct product version), which bear the respective Ex-marking “PTB 18 ATEX 5003 X” / “IECEx PTB 18.0004X” on the housing
- **Current-Voltage Measuring Module:** special DRP (dry-running protection) devices are to be applied, which bear the respective Ex-marking “PTB 18 ATEX 5003 X” / “IECEx PTB 18.0004X” on the housing. In the range 0.3 A .. 200 A they are executed as straight-through transformers, in the range 200 A ... 630 A they feature a bar connection.

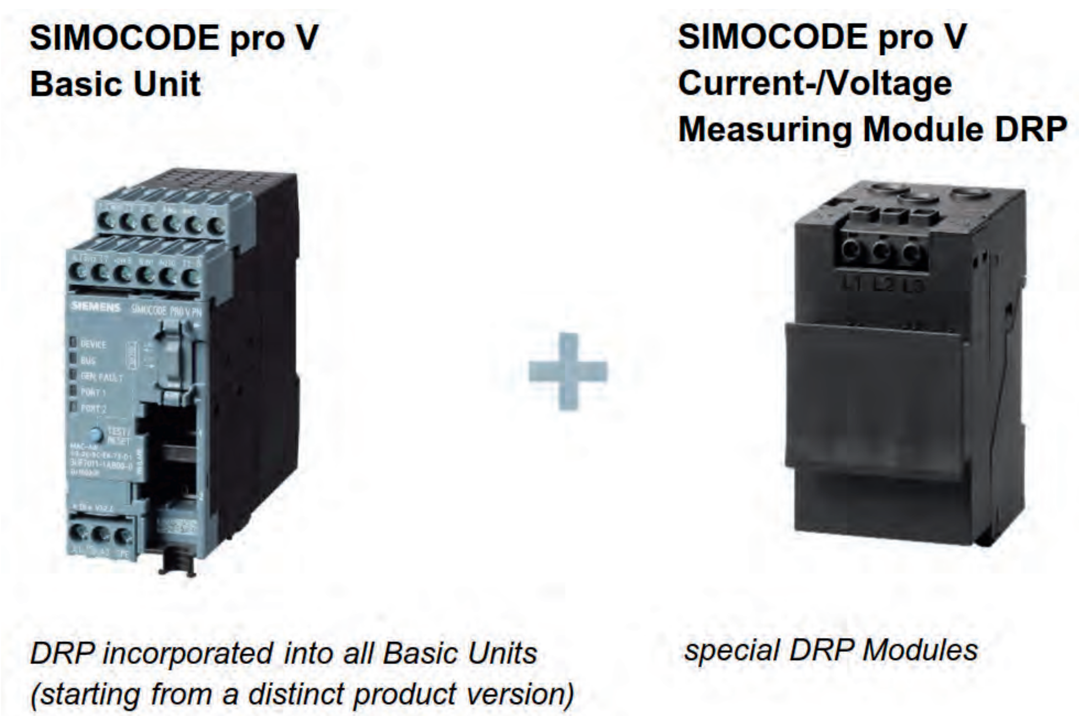

Fig. 4.1: : left: SIMOCODE pro V Basic Unit (example for communication through Profinet PN);
right: SIMOCODE pro V Current-/Voltage Measuring Module IUM with DRP function (example for straight-through transformer)

The interaction of the SIMOCODE components is shown in Fig. 4.2 The protection function “Dry-running protection for centrifugal pumps” is activated, as soon as the motor contactor is closed. Within the Current-/Voltage Measuring Module, active power values are calculated from the measured currents and voltages of the 3 phases and are transmitted to the Basic Unit (1). There the active power values P are compared with the deposited active power trip level P_{TRIP} (2). If the system is not in the start-up bridging phase and if an undercut $P < P_{TRIP}$ prevails throughout the complete delay time $t_{V,TRIP}$, a signal for “motor off” is generated in the Basic Unit and sent to the motor contactor, which disconnects the motor from the power supply line (3). At the same time, an error message is generated.

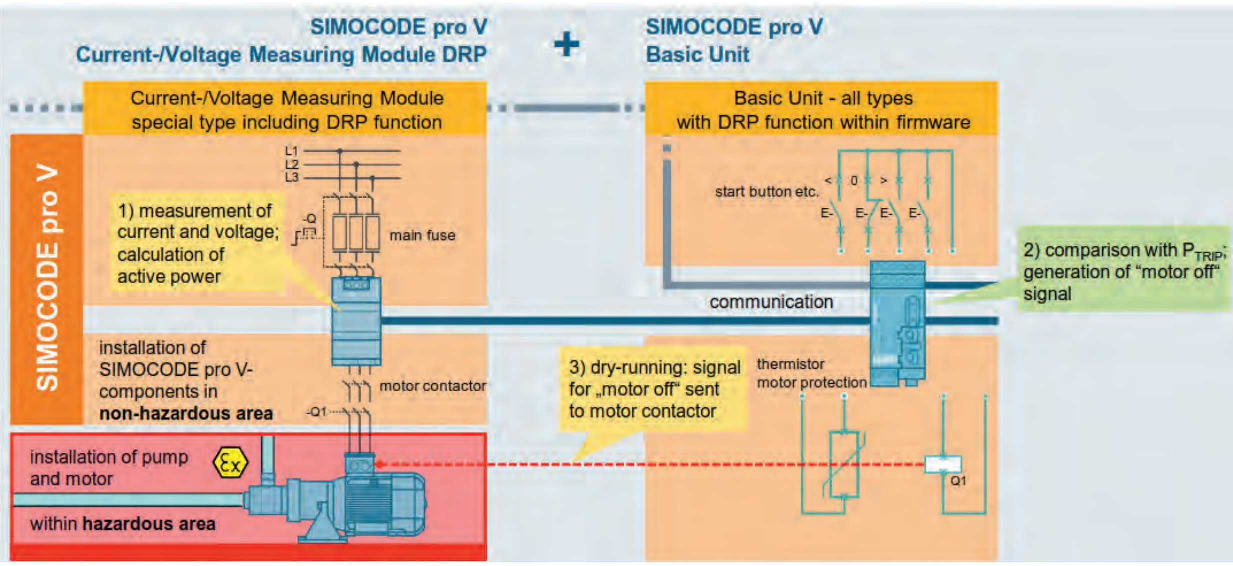

Fig. 4.2: Interaction of SIMOCODE devices for protection function „Dry-running protection for centrifugal pumps“ [6]

For practical applications in production plants it is mandatory, that the same SIMOCODE pro components (meaning physical devices with the same functionality) must be used both for deduction of the P_{TRIP} value and for realization of the shut-down function.

4.2 Motor protection

In addition to the dry-running protection, the SIMOCODE pro V hardware combination explained in Section 4.1 simultaneously provides motor protection functions, which are also ATEX-approved. The following functions are integrated into all Basic Units and Current-/Voltage Measuring Modules (starting from a distinct product version), which bear the respective Ex-marking “BVS 06 ATEX F 001” on their housings:

- **Overload protection:** Current-dependent electronic protection of three-phase and AC motors with adjustable tripping characteristics (class times) according to IEC 60947-4-1 [7] requirements.
- **Unbalance protection:** Protects motors from excessive temperatures caused by excessive phase unbalances. A definable and delayable response can be triggered.
- **Stalled rotor protection:** Immediate trip after the motor current overshoots an adjustable stalled rotor protection level (current threshold). With this feature, the motor can be shut down independently of the overload protection.
- **Thermistor protection:** the SIMOCODE pro V Basic Unit provides the option of connecting thermistor sensors (binary PTC) for monitoring of the motor temperature. The resistance of the thermistor increases rapidly when the temperature limit is reached. When this effect is registered in the Basic Unit, a trip of the motor can be triggered.

5 Summary and conclusion

5.1 Boundary conditions for application of dry-running protection by active power monitoring

The boundary conditions for application of the SIMOCODE pro V protection function "Dry-running protection for centrifugal pumps" by active power monitoring can be summarized as follows:

- SIMOCODE pro (electrical device) acts as "safety, controlling or regulating device" for type of protection control of ignition sources "b" with ignition protection type b1 and itself is installed outside of potentially explosive atmospheres. The respective Ex-marking "PTB 18 ATEX 5003 X" / "IECEx PTB 18.0004X", which defines the use cases, is imprinted on the housings of the SIMOCODE hardware components.
- The non-electrical equipment (centrifugal pump), which is to be protected, is used for conveying flammable fluids and/or is installed and operated in potentially explosive atmospheres. It determines the conformity assessment approach. Dry-running of the pump is to be avoided by SIMOCODE pro, in order to prevent potential ignition sources ("hot surface" and "mechanical spark") inside and outside of the pump from becoming effective.
- SIMOCODE pro fulfills the requirements of SIL 1 according to IEC 61508 ([1], [2]).
- For SIMOCODE pro, an EU-Type Examination Certificate [3] according to ATEX (EU Directive 2014/34/EU [10]) and a Certificate of Conformity [4] according to IECEx are available, thus facilitating utilization both within the EU and world-wide. Specific conditions for use are listed in the certificates. The conformity assessment approach has been executed according to ISO standards 80079-36 [9] and 80079-37 [14].
- The dry-running protection function can be applied to centrifugal pumps with progressive pump (conveying) characteristics (i.e., with radial impeller). Precondition is sufficient progressiveness of the active power curve, expressed as sufficient difference of the effective powers P_{MIN} at minimum flow rate and P_{OPT} at the operating point (P_{MIN} / P_{OPT} < 0.80). The overwhelming part of centrifugal pumps basically fulfills this requirement, however the combination of pump + motor has to be regarded for active power considerations, and correct dimensioning of the motor is necessary (no extreme oversizing).
- Boundary conditions for motors - given by the applicability of SIMOCODE pro as control product:
  - motor start-up method direct on line (DOL)
  - motor operation mode fixed speed (no frequency converters)
  - motor nominal voltage 110 V ... 690 V
  - motor nominal current 0.3 A ... 630 A
- Pump operation can be both continuously and discontinuously.
- There is <u>no</u> limitation regarding the sealing method of the centrifugal pump, thus applicable to e.g.:
  - mechanical seal – single acting or double acting
  - magnetic coupling
  - oanned motor pump [15]
  - gland sealing
- The following set of monitoring parameters is to be defined in the SIMOCODE parameter settings:
  - active power trip level P_{TRIP} (recommendation: $P_{TRIP} = 1.1 \times P_{MIN}$ with P_{MIN} as the active power at minimum allowable flow rate Q_{MIN})
  - delay time $t_{V,TRIP}$ during continuous operation (range 0 ... 10 s, default 0.5 s)
  - start-up bridging time t_{BRIDGE} for starting the pump with (partly) closed valve on the discharge side (range 0 ... 60 s, default 0 s)
- For every practical application within a plant, the same SIMOCODE pro components (meaning physical devices with the same functionality and ???) must be used both for deduction of the P_{TRIP} value and for realization of the shut-down function.

- Automatic re-starting of the drive motor must be prevented, after a trip has been initiated.
- The monitoring parameters can be directly entered into the SIMOCODE pro parameter settings with the help of the Engineering Software SIMOCODE ES (within the TIA portal framework), however it is strongly recommended to determine the active power trip level as $P_{TRIP} = 1.1 \times P_{MIN}$ by a so-called Teach-in procedure under operating conditions.
- Checks of the monitoring parameter settings must be performed after significant modifications of the plant. Checks of proper operation of the monitoring device must be executed at certain intervals (as given by the authorities or at least every 3 years).
- The pump must be commissioned and operated in compliance with the specifications provided by the pump manufacturer. In particular, the pump must be filled with liquid before start-up.
- SIMOCODE pro can simultaneously be used for ATEX-certified overload (according to IEC 60947-4-1 [7]) and thermistor protection of explosion-proof motors (Ex-marking “BVS 06 ATEX F 001” on the housings of the SIMOCODE hardware components).

5.2 Conclusion

Dry-running protection by active power monitoring with SIMOCODE pro is advantageous, especially since no further sensor is necessary, and any required or desired trip level can be defined. The method has been thoroughly tested with different pump and motor types, the switch-off function proofed to be very reliable and instantaneous, the procedure for determination and input of the necessary parameters is practicable. The ranges of application are clearly defined. Approval by authorities has been given with certificates according to ATEX and IECEx.

Thus, active power monitoring can be considered by pump manufacturers, project engineers and plant operators as reliable and effective method for dry-running protection of centrifugal pumps. Special advantage can be drawn from the simultaneous use of SIMOCODE pro for motor overload protection.

References

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Abbreviations

AC	alternating current
ATEX	ATmosphere EXplosive
CoC	Certificate of Conformity (according to IECEx)
DOL	direct on line
ES	engineering software
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
PN	Profinet
PTB	Physikalisch-Technische Bundesanstalt
PTC	positive temperature coefficient
SIL	safety integrity level
TIA	Totally Integrated Automation

$_{BRIDGE}$	bridging
$_{MAX}$	maximum
$_{MIN}$	minimum
$_{OPT}$	optimum, operation point
$_{TEMP}$	temporary
$_{TRIP}$	trip, shut-down

Biographies

The author **Albert Reichl** is Project Manager for Siemens DI PA SE&C EC.
He has been working for more than 25 years in the fields of engineering and process development for the chemical industry. The Siemens unit EC („Engineering & Consulting“) is especially engaged in consolidating process know-how with automation know-how.

The author **Bernhard Neumann** is Product Manager for Siemens SI CP PRM CM.
He is in responsible for the entire product life cycle of the motor control device SIMOCODE pro, especially with respect to new features. One important activity of the Siemens unit SI CP ("Smart Infrastructure Control Products") is the development and the manufacturing of SIMOCODE pro. Having entered the market in the early 1980s, SIMOCODE pro has been successful ever since due to continuous improvement.

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Part II

Dry-Running Protection of Centrifugal Pumps in Ex-Atmospheres

Benefits of Active Power Monitoring with SIMOCODE pro

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Contents

Part II

Test trials and certification for ATEX and IECEx applications

Abstract

Dry-running protection is mandatory for safe operation of centrifugal pumps, which are used for conveying flammable fluids and/or are installed in potentially explosive atmospheres.

While pump manufacturers must perform an ignition hazard assessment, project engineers have to identify the adequate protection method in co-operation with plant operators, who have to integrate it into their explosion protection concept and bear the responsibility for safe operation.

One possible indirect method for dry-running protection is monitoring of the active power and switching off the motor and thus the pump when a certain active power level is undercut (indication for dry-running). This can be realized with the SIMOCODE pro motor control device, which provides the dry-running protection function, but itself is installed in a switchboard outside of potentially explosive atmospheres. The method is especially suited for centrifugal pumps with radial impellers, which are operated continuously. Main advantages of this indirect "software" solution are the adjustability of the trip value, the applicability to all media (regardless of their characteristics, e.g. corrosivity) and the absence of inline sensors (allowing simple retrofit solutions).

With active power monitoring, explosion protection is provided by control of ignition sources at the pump. The safety device fulfills the requirements of SIL 1 according to the classification of IEC 61508. The conformity assessment has been executed by employing the international standards ISO 80079-36 and ISO 80079-37. For the respective SIMOCODE hardware components, an EU-Type Examination Certificate for dry-running protection of centrifugal pumps based on 2014/34/EU (ATEX) and an IECEx Certificate of Conformity (CoC) are available, thus enabling world-wide application.

In addition to pump protection, the installed SIMOCODE pro components also serve as ATEX-certified overload and thermistor protection device for explosion-proof motors.

This paper as **Part II** (of 2) outlines the test trials, which were conducted in the course of the development of the method in order to proof its effectiveness. Furthermore, the field of directives and standards is highlighted by explaining the Ex-markings of the SIMOCODE devices and the resulting use cases for Ex-protection as well as possible contributions of the method to an ignition hazard assessment (to be compiled by the pump manufacturer) and to an explosion protection concept (to be compiled by the plant operator).

The separate paper on **Part I** describes the basics for the application of active power monitoring with SIMOCODE pro as protection technique, including the required monitoring parameters and the determination of the active power trip level by a so-called Teach-in procedure. Besides that, the functionality and the interaction of SIMOCODE components for ATEX-approved dry-running protection of pumps are characterized, together with elementary statements on the possibility of simultaneous ATEX-approved motor protection.

1 Introduction

Due to their robust and unpretentious construction features, centrifugal pumps are and will be widely used in production plants within the process industries for conveying liquid fluids. For the overwhelming part of the applications they are combined with an electrical motor driven by 3-phase alternating current (AC). Dry-running of centrifugal pumps immediately poses serious threats. A material damage of the pump (starting with the sealing) is likely to happen after a very short time period due to the missing lubrification effect of the liquid.

In case the conveyed liquid is flammable, an explosive atmosphere can be built up inside the pump by the gas/vapor phase together with oxygen (e.g. from air ingress) under dry-running conditions. Simultaneously, the appearance of an ignition source (e.g. hot surface or mechanical spark) inside the pump can occur, which together would most likely lead to an explosion.

Hot surfaces also constitute potential ignition sources at the outer surface of the pump. [8] Explosion risks outside of the pump can be enhanced by the emission of flammable substances from the pump due to the material damage.

Considering all this, dry-running of centrifugal pumps must be prevented by all means whenever flammable substances can be present inside the pump or outside in the vicinity of the pump. Therefore, effective and reliable monitoring has to be applied, which will initiate a shut-down of the motor and thus of the pump in case of violation of appropriate limits.

2 Methods for dry-running protection of centrifugal pumps

2.1 Conventional methods employing additional sensors

Several conventional methods for dry-running protection of pumps are applied in the different branches of process industries (e.g. chemical industry). They are all sensor-based, requiring costs for hardware, installation and maintenance and making their functionality depending on the location of the installation and on potential risks of fouling and corrosion.

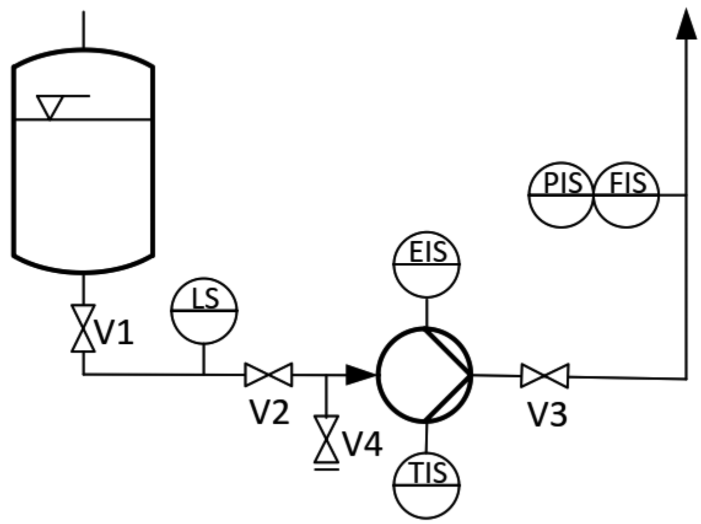

Fig. 2.1: conventional sensors for dry-running protection of pumps

Choice of the sensor (or of a combination) has in the end to be performed by the plant operator (usually assisted by the project engineer) and is depending on the specific requirements for protection. The most common sensors and their characteristics are (see Fig. 2.1):

- level switch LS (suction side): widely used in process industries, under the precondition that fouling and corrosion can be controlled. However, level switches might give false alarm when gas or vapor bubbles or vibrations of the pipeline occur. Furthermore, no trip level can be set – there is only a digital signal 0 or 1. In case valve V2 is closed by mistake or the line is blocked on the discharge side, dry-running of the pump will not be detected. In case valve V3 is closed by mistake, "internal" pump operation at zero external flow and potential overheating will also not be detected.
- flow sensor/switch FIS (discharge side): gives a direct indication of the flow rate. However, the location and especially sufficient lengths of inlet and outlet paths are critical. During operation, delay periods as well as potential false alarms by solid particles have to be considered.
- pressure sensor/switch PIS (discharge side): both zero flow (low pressure) and zero external flow (with blocking downstream of sensor – high pressure) will be detected. The system, however, is very sensitive towards blocking of the measuring tube and false alarm by gas or vapor bubbles or vibrations.
- temperature sensor/switch TIS: gives a direct indication for potential ignition source "hot surface". The correct location of the sensor (usually directly at the surface of the pump or in the close vicinity) is decisive. Delay periods caused by the procedure of heat conduction and by the sensor itself have to be considered.

All the conventional methods have in common that they employ an additional sensor, thus dry-running protection is realized as a functional chain (sensor – control unit – motor feeder, see Fig. 2.2) of devices from different suppliers. For use in hazardous areas, proof of correct interaction and of compliance with SIL (safety integrity level) requirements (as defined in IEC 61508 [1]) has to be individually executed by the plant operator.

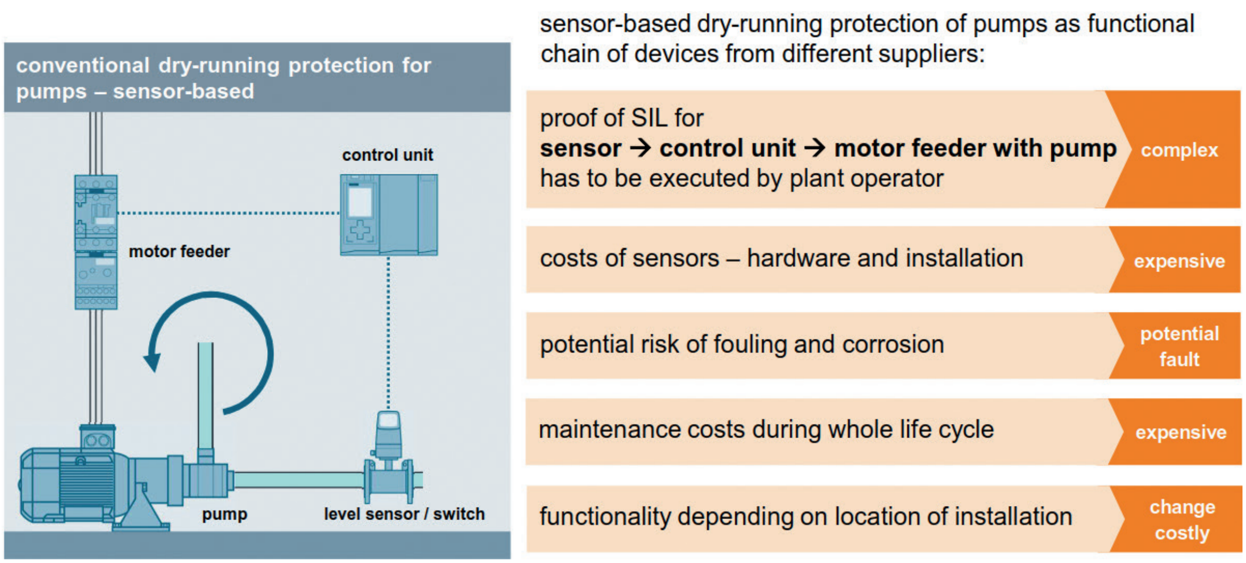

Fig. 2.2: Functional chain of conventional methods for dry-running protection

2.2 Active power monitoring with SIMOCODE pro V using motor data (without extra sensor)

Another very effective measure for dry-running protection is monitoring of the active power required by the motor, e.g. with the help of the motor control device SIMOCODE pro V. For centrifugal pumps with radial impellers (as applied in the very most cases) there is a clear, progressive dependence of the active power and the flow rate – the higher the flow rate, the higher the active power (see Fig. 2.3). Thus, if the active power value falls below a defined minimum value, this means an indication for dry-running conditions, and the motor is switched off by the control device. Depending on the requirements of the explosion protection concept (see [11] for the necessity of this document) of the plant operator, the use of active power monitoring for dry-running protection is conceivable as a stand-alone solution, or in combination with other monitoring devices, e.g. one of the aforementioned measures.

With active power monitoring, the critical state of "internal" pump operation (closed valve or blockade on discharge side) at zero external flow (danger of overheating with potential ignition source "hot surface") will be reliably detected. Gas bubbles, which might contain oxygen from air ingress, will lead to a considerable drop in active power and thus to a fast shutdown, whereas vapor bubbles caused by cavitation on the suction side will to a certain extent collapse due to pressure increase in the pump and will only be of remarkable impact on the active power in case of unwanted strong cavitation.

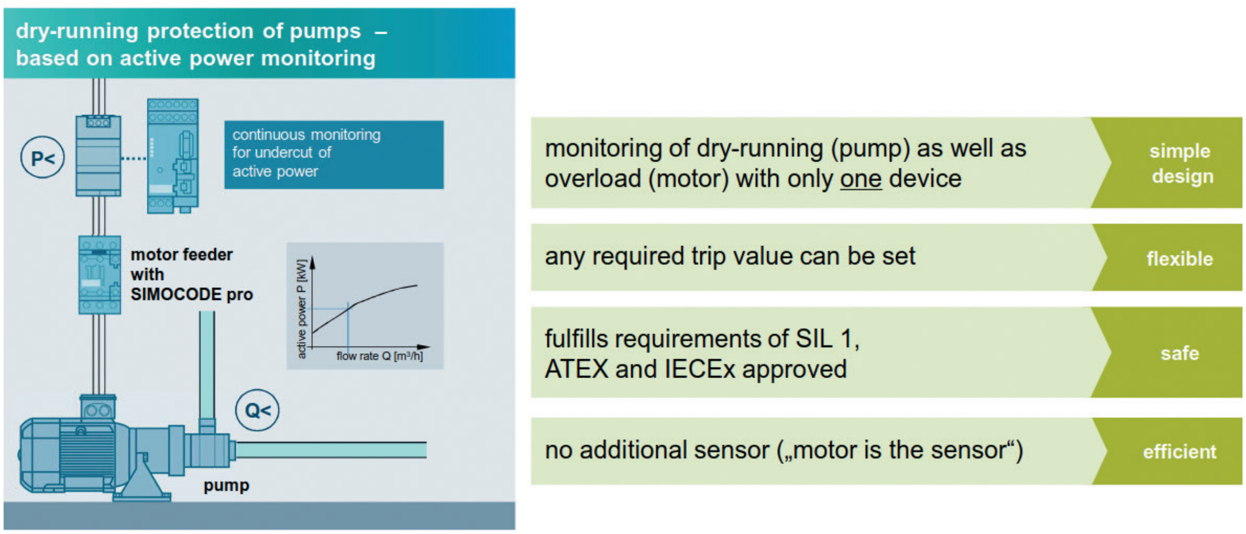

Fig. 2.3: Functional chain of active power monitoring (undercut of defined minimum value) for dry-running protection

SIMOCODE pro V fulfills the requirements of SIL 1 following the classification of IEC 61508 [1] (see certificate [2]) for dry-running protection and is approved for applications according to ATEX [3] and IECEx [4]. No additional hardware devices have to be installed for the dry-running protection function of SIMOCODE pro V, the motor acts as a sensor. However, attention has to be drawn to the definition of the values of the monitoring parameters to be set in SIMOCODE pro V, especially to the determination of the adequate and required active power trip level.

As a further benefit, the SIMOCODE components used for dry-running protection can simultaneously maintain the motor protection, for which an ATEX-certification is also available [5].

3 Test trials for proof of effectiveness of active power monitoring for dry-running protection

In the course of the development and the certification process for the SIMOCODE protection function “Dry-running protection for centrifugal pumps”, intensive test trials have been performed. Part of these tests have been planned together and witnessed by the Notified Body PTB (Physikalisch-Technische Bundesanstalt).

3.1 Pump testing facility

The majority of the tests was carried out at a pump testing facility of Bilfinger Maintenance GmbH in Industriepark Hoechst, Frankfurt/Germany. The flow diagram of the facility is shown in Fig. 3.1. Water was circulated with the pump P-101 (driven by motor EM-101), the flow rate was measured with the calibrated magnetic inductive flow meter FI102. With the manual control valve Y-100, the flow rate downstream of pump P-101 could be regulated throughout the complete range of the pump characteristic curve (from minimum flow rate Q_{MIN} to operating point Q_{OPT} and further to maximum flow rate Q_{MAX}). For motor management and control purposes, a SIMOCODE pro V Basic Unit and a Current-/Voltage Measuring Module were connected to the motor EM-101. With the SIMOCODE components, active power values were measured and the effectiveness of respective values of the monitoring parameters P_{TRIP} (active power trip level), $t_{V,TRIP}$ (delay time at continuous operation) and t_{BRIDGE} (start-up bridging time) was tested. In parallel, active power values were recorded by a calibrated Fluke 434 II Three Phase Power Analyzer.

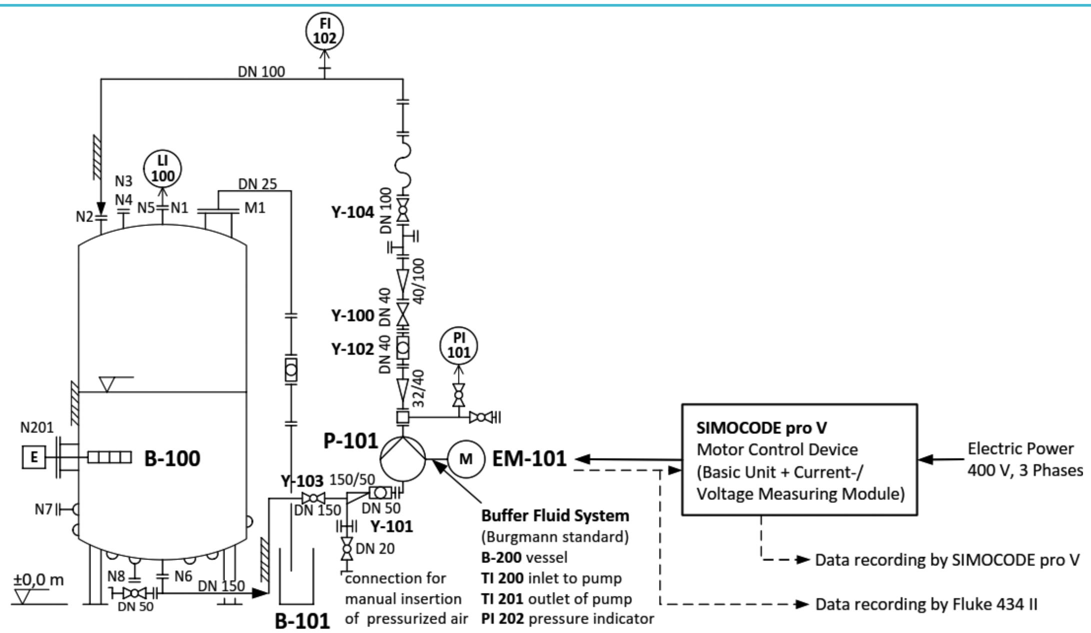

Fig. 3.1: Flow diagram of the pump testing facility of Bilfinger Maintenance GmbH in Industriepark Hoechst, Frankfurt/Germany

3.2 Test program

As pump P-101, a variety of pump types of different sizes and sealing methods has been tested, combined with motors EM-101 with different speeds – see compilation in Table 3.1. Such pump types were selected, which are widely used in process industries. Both new pumps/motors as well as units which had already been in operation for production purposes have been examined. By setting respective values of Q_{MIN} and Q_{OPT} with the help of manual valve Y-100, the active power ratios at minimum and optimum flow rate were determined and were in the range of $0.44 \leq P_{MIN} / P_{OPT} \leq 0.76$ for the different combinations of pump + motor and thus below the required limit of $P_{MIN} / P_{OPT} < 0.80$. Values for the active power trip level P_{TRIP} were deducted from P_{MIN} (at minimum flow rate Q_{MIN}) and entered into the SIMOCODE parameter settings. The other two monitoring parameters delay time $t_{V,TRIP}$ during continuous operation (0 ... 10 s) and start-up bridging time t_{BRIDGE} (0 ... 60 s) were varied throughout the complete set-up range.

	Allweiler CNH-B 80-50-200	**Richter MNK/F 50-32-200**	**Munsch NPC 50-32-160**	**KSB Etabloc 040-025-160**
impeller	Ø 205 mm, disks on both sides	Ø 210 mm, disks on both sides	Ø 181 mm, disks on both sides	Ø 135 mm, disks on both sides
sealing	double acting mechanical seal	magnetic coupling	double acting mechanical seal	single acting mechanical seal
pump shaft power (nominal)	15 kW	1.44 kW	1.5 kW	0.80 kW
year of manufacture	2011	2017	2016	2018
motor	ATB/F+G CD 180M-2Y3A, three-phase AC motor, IE3	ATB/F+G CD 100L1-4Y3, three-phase AC motor, IE3	ATB/F+G CD 100L1-4Y3, three-phase AC motor, IE3	Siemens 90L, three-phase AC motor, IE3
motor nominal power	22 kW	2.2 kW	2.2 kW	2.2 kW
year of manufacture	2012	2011	2011	2018
quotient of active power at min and optimum flow rate $P_{MIN} / P_{OPT} < 0.80$	0.44	0.58	0.69	0.76
active power trip level $P_{TRIP} = 1.1 \times P_{MIN}$	7,700 W	1,035 W	1,030 W	913 W

Table 3.1: Features of centrifugal pumps and motors examined during test trials for SIMOCODE dry-running protection

3.3 Results: effect of parameters, switch-off function, active power recording, Teach-in

For all parameter settings, the monitoring of an undercut of active power and the switch-off function proofed to work very reliably. Values for delay time $t_{V,TRIP}$ and start-up bridging time t_{BRIDGE} were exactly matched with instantaneous consecutive reaction.

Fluctuations in recording of active power by SIMOCODE were mainly due to mechanical reasons (e.g. vibrations of the combination of pump P-100 and motor EM-101) and were in the range of ±3 %; discrepancies between SIMOCODE active power values and those of the calibrated Fluke 434 II were in the range of ±2 %.

The Wizard (assistant with dialogue windows) for Teach-in (method for determination of the active power trip level P_{TRIP} under operating conditions) was thoroughly and successfully tested with respect to functionality and operability, including the safety features (basic protection during Teach-in with an active power temporary trip level $P_{TRIP,TEMP} < P_{MIN}$ and timer for monitoring of inactivity). Direct input of the monitoring parameters with the help of the Engineering Software SIMOCODE ES led to the same impact of the parameters.

3.4 Results: behavior with gas bubbles

For testing the behavior of the system in the presence of gas bubbles, pressurized air was inserted upstream of pump P-101 (see Fig. 3.1); bubbles could be observed through the inspection glasses Y-101 (upstream) and Y-102 (downstream of pump P-101) – see Fig. 3.2. Only a small amount of bubbles was tolerated, with increasing intensity of bubbles the active power decreased rapidly and permanently, thus the motor was shut down by active power monitoring. This is in line with practical Ex-protection requirements, since gas bubbles could contain explosive mixtures.

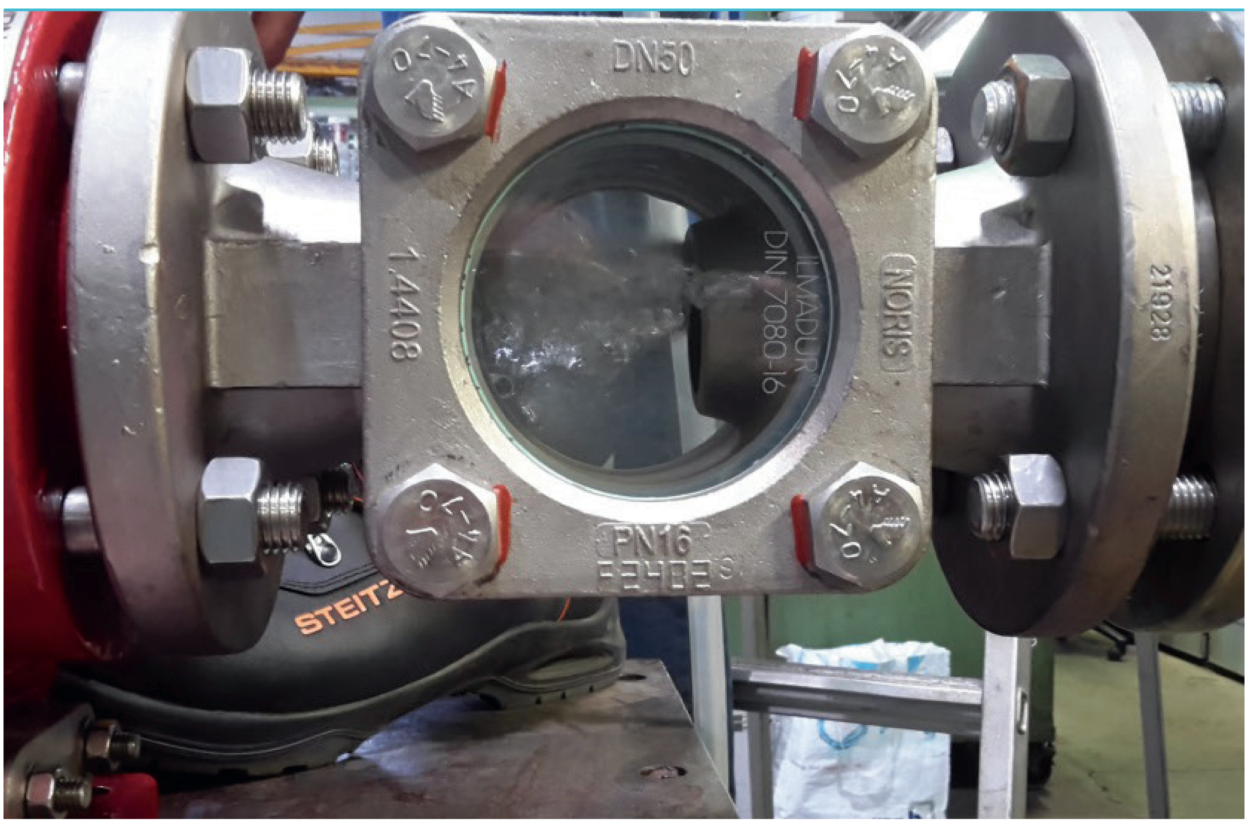

Fig. 3.2: Gas bubbles at inspection glass Y-101 (upstream pump P-101); trials at Bilfinger Maintenance GmbH with Richter MNK/F 50-32-200 [8]

3.5 Results: behavior with vapor bubbles

For testing the behavior of the system in the presence of vapor bubbles, valve Y-103 upstream of pump P-101 (see Fig. 3.1) was throttled, thus causing cavitation. To a noticeable extent, these bubbles collapsed in pump P-101 due to pressure increase, and no respectively little effect on active power was observed. However, when strong cavitation occurred (see Fig. 3.3), which in the long run would lead to mechanical pump damage, the active power decreased significantly, and the motor was shut down by active power monitoring. This is also in line with practical requirements, since vapor bubbles are not explosive due to the absence of oxygen, however pump damage should nevertheless be prevented.

Fig. 3.3: Strong cavitation effects at inspection glass Y-101 (upstream pump P-101) – approximately 1/3 of glass filled with vapor; trials at Bilfinger Maintenance GmbH with Richter MNK/F 50-32-200

4 Ex-marking and certification for ATEX and IECEx applications

Note: The following section only relates to the SIMOCODE protection function "Dry-running protection for centrifugal pumps" aiming at a **non-electrical equipment** (centrifugal pump). For ATEX-related motor **(electrical equipment)** protection, different considerations have to be made.

4.1 Ignition hazard assessment and explosion protection concept

According to standard ISO 80079-36 [9], an **ignition hazard assessment** must be performed for non-electrical equipment (e.g. centrifugal pump), which is intended for use in potentially explosive atmospheres and protected by control of ignition sources "b". By executing this, proof of compliance with basic safety and health requirements according to ATEX directive 2014/34/EU [10] is done. For centrifugal pumps, the ignition hazard assessment is performed by the **pump manufacturer**.

The **plant operator** is responsible for the **explosion protection concept** of the plant and for correct application of the equipment. Together with planning engineers he selects appropriate protection devices or methods for operation of equipment in potentially explosives atmospheres. The plant operator must compile an explosion protection document according to ATEX directive 1999/92/EC [11].

One possible method for the control of ignition sources at centrifugal pumps is active power monitoring with the help of SIMOCODE. The Motor Management and Control Device SIMOCODE pro is an electrical equipment and a "safety, controlling or regulating device" for type of protection control of ignition sources "b" with ignition protection type b1, which itself is installed outside of potentially explosive atmospheres. However, it is intended to protect a non-electrical equipment (centrifugal pump), which is used for conveying flammable fluids and/or is installed and operated in potentially explosive atmospheres and which determines the approach for the conformity assessment. In other words, explosive atmospheres can occur both inside the pump and outside (see Fig. 4.1). Ignition protection type b1 means according to ISO 80079-37 [14]: a suitable level of reliability, assembled and installed in accordance with any relevant standards, adopting well tried safety principles, able to withstand expected influences during operation; if a control parameter passes a critical value, action is taken to minimize the likelihood of the ignition source becoming effective. The SIMOCODE protection function "Dry-running protection for centrifugal pumps" contributes to the control of the ignition hazards "hot surface" and "mechanical spark" at the pump – to prevent them from becoming effective. Thus, it can be integrated by the pump manufacturer as prevention method into the ignition hazard assessment (for an example see [6]), and it can be considered by the plant operator as protection method.

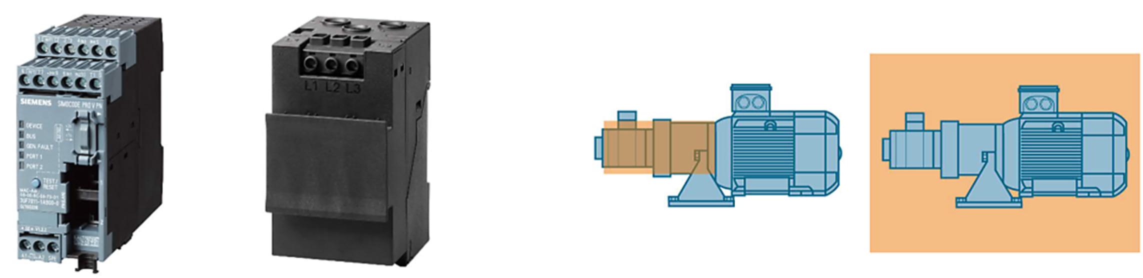

Fig. 4.1: SIMOCODE pro V and centrifugal pump – combination of electrical and non-electrical explosion protection

4.2 Explanation of Ex-marking and use cases for Ex-protection

The development of the SIMOCODE protection function “Dry-running protection for centrifugal pumps” has been performed in co-operation with Physikalisch-Technische Bundesanstalt (PTB), which in the end issued an EU Type-Examination Certificate [3] (related to ATEX directive 2014/34/EU [10]) and an IECEx Certificate of Conformity (CoC) [4]. The ATEX certificate facilitates use within the EU, whereas the IECEx CoC potentially enables world-wide use; additional, but mostly formal national approvals may be required for each country. The conformity assessment approach (i.e., that the protection method is suited for control of ignition sources) has been performed according to ISO 80079-36 [9] and ISO 80079-37 [14] and is acknowledged both for the ATEX- and the IECEx-certification.

The applicability of the protection function with respect to Ex-zones can be explained by analyzing the respective Ex-marking, which is listed in both certificates and is imprinted on the housings of the Basic Unit and of the Current-/Voltage Measuring Module:

		for use of the pump (equipment to be protected) in:
PTB 18 ATEX 5003 X **IECEx PTB 18.0004X**	I (1G/M2) [Ex h Ga/Mb]	*potentially explosive atmospheres in mines*
	Ex II (1/2) G [Ex h Ga/Gb]	*potentially explosive atmospheres caused by gas/vapor/mist*
	II (1G/2D) [Ex h Ga/Db]	*potentially explosive atmospheres caused by dust*

In a first analyzation step, the Ex-marking can be divided into segments with the following meaning:

PTB 18	**ATEX**	**5003**	**X**			
abbr. of Noti-fied Body and year of issue		sequential no. of EU-Type Examination Certificate	indication that the prod-uct is subject to specific conditions for use	Ex	I (1G/M2) II (1/2) G II (1G/2D)	[Ex h Ga/Mb] [Ex h Ga/Gb] [Ex h Ga/Db]
IECEx	**PTB**	**18.0004**	**X**	directive-related section (2014/34/EU)		standard-related section (ISO 80079-36; ISO 80079-37; IEC 60079-0)
	Control Body (abbr.)	sequential no. of COC Certificate of Conformity	indication that the product is subject to specific conditions for use			

In a second analyzing step, the directive-related section and the standard-related section have to be investigated.

Explanation of the ”directive-related section”:

abbr.	**meaning**	**explanation**	**reference**
I	equipment-group	equipment intended for use in mining	2014/34/EU [10]
II	equipment-group	equipment intended for use in all other places than mining	2014/34/EU [10]
(xx/yy)	equipment category	xx = inside of the equipment – connected to areas, which at least require the level of protection of the specified equipment category yy = outside of the equipment – installed in areas, which at least require the level of protection of the specified equipment category	2014/34/EU [10]
	(..) parentheses	Equipment with Ex-marking in parentheses itself is not intended for installation in areas with potentially explosive atmospheres, however it is part of an ignition prevention system for an equipment, which is intended for installation in areas with potentially explosive atmospheres.	

Explanation of the “standard-related section”:

abbr.	meaning	explanation	reference
[Ex h ...]	h	marking for non-electrical equipment intended for installation in potentially hazardous areas This marking does not define a specific type of protection (e.g. control of ignition sources).	ISO 80079-36 [9]
	[..] brackets	Equipment with Ex-marking in brackets itself is not intended for installation in areas with potentially explosive atmospheres, however it is part of an ignition prevention system for an equipment, which is intended for installation in areas with potentially explosive atmospheres.	IEC 60079-0 [12] ISO 80079-37 [14]
[... Xx/Yy]	EPL (Equipment Protection Level)	Xx = inside of the equipment – connected to areas, which at least require the specified EPLn Yy = outside of the equipment – installed in areas, which at least require the specified EPL	ISO 80079-36 [9]

According to the symbols of the Ex-marking, SIMOCODE pro V gives protection for use cases of centrifugal pumps, which are identified by the following equipment categories, Ex-zones and EPLs:

Inside of the pump:

- oth equipment-groups I and II (2014/34/EU); equipment category 1G for equipment with a very high level of protection, for use in areas in which explosive atmospheres caused by gas/vapor/mist are present continuously, for long periods or frequently – corresponding to Ex-zone 0
  - accordingly: EPL Ga (ISO 80079-36): very high protection level

It must be noted that Ex-zone 0 applications are of very little practical relevance (e.g. submersible pumps or drum pumps [16]); moreover Ex-zone 2 or sometimes Ex-zone 1 will occur, however permission for Ex-zone 0 applications includes Ex-zone 1 and Ex-zone 2.

Outside of the pump:

equipment categories and explosive atmospheres have to be distinguished

- equipment-group I “mining” (2014/34/EU); equipment category M2 for equipment with a high level of protection, for mines likely to be endangered by firedamp and/or combustible dust
- accordingly: EPL Mb (ISO 80079-36): high protection level
- equipment-group II “non-mining” (2014/34/EU), equipment category 2G for equipment with a high level of protection, for use in areas in which explosive atmospheres caused by gas/vapor/mist are likely to occur occasionally – corresponding to Ex-zone 1
  - accordingly: EPL Gb (ISO 80079-36): high protection level
- equipment-group II “non-mining” (2014/34/EU), equipment category 2D for equipment with a high level of protection, for use in areas in which explosive atmospheres caused by air/dust mixtures are likely to occur occasionally – corresponding to Ex-zone 21
  - accordingly: EPL Db (ISO 80079-36): high protection level

Permission for Ex-zone 1 applications includes Ex-zone 2, and Ex-zone 21 includes Ex-zone 22, respectively.

Important note:

- For applications with Ex-zone 0 (which are of little practical relevance), additional measures are necessary besides SIMOCODE pro V to achieve the necessary level of protection for the pump.
- For applications with Ex-zones 1, 2, 21 or 22, SIMOCODE pro V might be used as sole protection method for the pump. From case to case, additional measures might be necessary to achieve the required ignition protection.
- However, any utilization of SIMOCODE pro V for control of ignition sources respectively explosion protection of centrifugal pumps has to be considered in the frame of and is depending on the explosion protection concept of the plant operator.

As stated in the above description of the Ex-marking, the letter "X" in the certificate number means specific conditions for use, which must be obeyed. These specific conditions of use are listed both in the EU Type-Examination Certificate [3] and in the IECEx Certificate of Conformity [4]. Basically, they are contained in and correspond with the peculiarities for application, which are described in this paper and which are summarized as boundary conditions in the next section.

5 Summary and conclusion

5.1 Boundary conditions for application of dry-running protection by active power monitoring

The boundary conditions for application of the SIMOCODE pro V protection function "Dry-running protection for centrifugal pumps" by active power monitoring can be summarized as follows:

- SIMOCODE pro (electrical device) acts as "safety, controlling or regulating device" for type of protection control of ignition sources "b" with ignition protection type b1 and itself is installed outside of potentially explosive atmospheres. The respective Ex-marking "PTB 18 ATEX 5003 X" / "IECEx PTB 18.0004X", which defines the use cases, is imprinted on the housings of the SIMOCODE hardware components.
- The non-electrical equipment (centrifugal pump), which is to be protected, is used for conveying flammable fluids and/or is installed and operated in potentially explosive atmospheres. It determines the conformity assessment approach. Dry-running of the pump is to be avoided by SIMOCODE pro, in order to prevent potential ignition sources ("hot surface" and "mechanical spark") inside and outside of the pump from becoming effective.
- SIMOCODE pro fulfills the requirements of SIL 1 according to IEC 61508 ([1], [2]).
- For SIMOCODE pro, an EU-Type Examination Certificate [3] according to ATEX (EU Directive 2014/34/EU [10]) and a Certificate of Conformity [4] according to IECEx are available, thus facilitating utilization both within the EU and world-wide. Specific conditions for use are listed in the certificates. The conformity assessment approach has been executed according to ISO standards 80079-36 [9] and 80079-37 [14].
- The dry-running protection function can be applied to centrifugal pumps with progressive pump (conveying) characteristics (i.e., with radial impeller). Precondition is sufficient progressiveness of the active power curve, expressed as sufficient difference of the effective powers P_{MIN} at minimum flow rate and P_{OPT} at the operating point ($P_{MIN} / P_{OPT} < 0.80$). The overwhelming part of centrifugal pumps basically fulfills this requirement, however the combination of pump + motor has to be regarded for active power considerations, and correct dimensioning of the motor is necessary (no extreme oversizing).
- Boundary conditions for motors - given by the applicability of SIMOCODE pro as control product:
  - motor start-up method direct on line (DOL)
  - motor operation mode fixed speed (no frequency converters)
  - motor nominal voltage 110 V ... 690 V
  - motor nominal current 0.3 A ... 630 A
- Pump operation can be both continuously and discontinuously.

- There is no limitation regarding the sealing method of the centrifugal pump, thus applicable to e.g.:
  - mechanical seal – single acting or double acting
  - magnetic coupling
  - canned motor pump [15]
  - gland sealing
- The following set of monitoring parameters is to be defined in the SIMOCODE parameter settings:
  - active power trip level P_{TRIP} (recommendation: $P_{TRIP} = 1.1 \times P_{MIN}$ with P_{MIN} as the active power at minimum allowable flow rate Q_{MIN})
  - delay time $t_{V,TRIP}$ during continuous operation (range 0 ... 10 s, default 0.5 s)
  - start-up bridging time t_{BRIDGE} for starting the pump with (partly) closed valve on the discharge side (range 0 ...60 s, default 0 s)
- For every practical application within a plant, the same SIMOCODE pro components must be used both for deduction of the P_{TRIP} value and for realization of the shut-down function.
- Automatic re-starting of the drive motor must be prevented, after a trip has been initiated.
- The monitoring parameters can be directly entered into the SIMOCODE pro parameter settings with the help of the Engineering Software SIMOCODE ES (within the TIA portal framework), however it is strongly recommended to determine the active power trip level as $P_{TRIP} = 1.1 \times P_{MIN}$ by a so-called Teach-in procedure under operating conditions.
- Checks of the monitoring parameter settings must be performed after significant modifications of the plant. Checks of proper operation of the monitoring device must be executed at certain intervals (as given by the authorities or at least every 3 years).The pump must be commissioned and operated in compliance with the specifications provided by the pump manufacturer. In particular, the pump must be filled with liquid before start-up.
- SIMOCODE pro can simultaneously be used for ATEX-certified overload (according to IEC 60947-4-1 [7]) and thermistor protection of explosion-proof motors (Ex-marking "BVS 06 ATEX F 001" on the housings of the SIMOCODE hardware components).

5.2 Conclusion

Dry-running protection by active power monitoring with SIMOCODE pro is advantageous, especially since no further sensor is necessary, and any required or desired trip level can be defined. The method has been thoroughly tested with different pump and motor types, the switch-off function proofed to be very reliable and instantaneous, the procedure for determination and input of the necessary parameters is practicable. The ranges of application are clearly defined. Approval by authorities has been given with certificates according to ATEX and IECEx.

Thus, active power monitoring can be considered by pump manufacturers, project engineers and plant operators as reliable and effective method for dry-running protection of centrifugal pumps. Special advantage can be drawn from the simultaneous use of SIMOCODE pro for motor overload protection.

References

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[10] ATEX 2014/34/EU, Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonization of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast)

[11] ATEX 1999/92/EC, Directive 1999/92/EC of the European Parliament and of the Council of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres (15th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)

[12] IEC 60079-0:2011, Explosive atmospheres – Part 0: Equipment – General requirements

[13] IEC 60079-17:2013, Explosive atmospheres – Part 17: Electrical installations inspection and maintenance

[14] ISO 80079-37:2016, Explosive atmospheres – Part 37: Nonelectrical equipment for explosive atmospheres – Nonelectrical type of protection constructional safety "c", control of ignition sources "b", liquid immersion "k"

[15] Himstedt, M., Krämer, St., Concept for explosion protection of canned motor pumps of category 2 G, 2nd International Rotating Equipment Conference, Session 9-1, Düsseldorf, 2012

[16] Himstedt, M., Explosion protection concept for liquid pumps of ATEX category 1, 1st International Rotating Equipment Conference, Session 4-1, Düsseldorf, 2008

Abbreviations

AC	alternating current
ATEX	ATmosphere EXplosive
CoC	Certificate of Conformity (according to IECEx)
DOL	direct on line
ES	engineering software
IEC	Internationale Electrotechnical Commission
ISO	International Organization for Standardization
PN	PROFINET
PTB	Physikalisch-Technische Bundesanstalt
PTC	Positive temperature coefficient
SIL	safety integrity level
TIA	Totally Integrated Automation

$_{BRIDGE}$	bridging
$_{MAX}$	maximum
$_{MIN}$	minimum
$_{OPT}$	optimum, operation point
$_{TEMP}$	temporary
$_{TRIP}$	trip, shut-down

Biographies

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