Innovative testing of advanced PLCs of sewage water pumping stations

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ABSTRACT:

The operational control of a pump system is realised with Programmable Logic Controllers (PLCs). Usually these PLC's are tuned during commissioning when the system is in operation. It is undesirable in critical systems to encounter malfunctioning PLCs, that may lead to damage. In complex waste water transportation systems the PLC behaviour cannot be tested completely, because the waste water supply is limited and cannot be controlled. For these kind of applications, WL Delft Hydraulics' simulation software for pipe system transients, WANDA, includes new functionality to link a numerical model to the actual PLC and hardware. The WANDA model feeds the PLC with generated measurements and the PLC performs its algorithm and returns control settings; i.e. pump speeds in this particular application. The WANDA model simulates normal and emergency scenarios, such that the actual PLC's response is evaluated. In fact, the PLC and control hardware is verified and tuned with "digital water". This innovative approach has been successfully applied to sewage water pumping stations in Amsterdam and Rotterdam.

1 INTRODUCTION

Automatic control systems have become common practice in the water industry during the last decade. These control systems have become more and more complex for a number of reasons. Firstly, advanced control systems help to reduce transient pressures during normal operations and emergency operations; an example is the installation of variable speed drives on sewage water pumps that are reduced to a certain minimum speed prior to shut-down. Secondly, control systems have become more complicated in order to optimise the energy consumption of a water distribution or collection system. Finally many existing systems are being stretched to their limits in the process of continuous debottlenecking, requiring advanced controls to maintain the operation within the feasible constraints.

The arguments above motivate the increasing attention for the design of the control system of a water network. Most of the transient simulation tools, like Flowmaster or WL Delft Hydraulics' WANDA, have functionality to simulate the dynamic behaviour of control systems in conjunction with the complete fluid dynamics, including transmission of pressure waves. However, despite the increasing complexity of the control systems, many Programmable Logic Controllers (PLCs) are tuned during commissioning of the system based on experience of the contractor. This old-fashioned on-the-spot tuning is acceptable for simple controllers, but not for complex control systems with several switches to handle exceptional situations or to handle pumping stations with several variable speed pumps.

The practical problem of these complex PLCs is that the system simply cannot be forced through the full range of system states and the exceptional situations, because the exceptional water demand or sewage supply is not present or the risk of severe damage is significant. Since 2005, these critical PLCs can be tested on-the-spot with "digital water", linking WANDA to the PLC and associated hardware.

2 TESTING A PLC WITH "DIGITAL WATER"

2.1 *The upgraded sewage water transportation system of Amsterdam*

The upgraded sewage water transportation systems of Amsterdam include 28 pumping stations and 4 booster pumping stations, which is an innovation of its own [1]. The in-line booster stations, comprising 3 to 6 pumps each, have to respond reasonably fast on variations in the suction pressure in order to maintain acceptable pressures in the mains.

The upgraded sewage water transportation system contain two main lines with a total length of 49 km, tranporting domestic water and storm water to the new treatment plant in West Port area. The booster pumps start when the discharge capacity of the pumping stations becomes insufficient to transport the supply to the treatment plant. The control philosophy of the booster stations is similar to standard sewage pumping stations: they start if the suction head exceeds the ON-level and maintain a certain target level while active. The next pump kicks in if the running pump(s) have reached the maximum speed. One pump trips if the running pumps have jointly reached the minimum speed. If the suction head drops below the OFF-level and the last pump runs at the minimum speed, then this pump trips and the booster stations switches to bypass mode.

The crucial difference between a normal pumping station and a booster station is the absence of a suction reservoir. This absence of storage capacity implies that the booster station suction head will fluctuate significantly faster than the suction level of a normal pumping station. WL | Delft Hydraulics has proven the feasibility of the booster stations in a sewage water transportation system in a specialist consultancy project for Waternet, Amsterdam [1]. The project showed that a robust control is feasible, based on local measurements only (suction pressure and booster station flow rate),despite the low pressure class of 4 bar only in the existing lines. One of the key conclusions of this feasibility study stated that the large, dominant, pumping stations should have stable, sufficiently smooth, controllers.

When the booster stations were ready for commissioning, most of the existing pumping stations were not yet switched to the new main lines. The scheduled period to switch over to the new transportation system was 3 months. Consequently, it could take weeks or months before the booster pumps would get into operation for the first time. But when the booster pumps start for the first time, it is imminent that the control system of the booster pumps and the large pumping stations behave in a similar way as in the simulation models. In order to test these control systems (PLC) and associated hardware in a safe way, while guaranteeing proper operation, Waternet has decided for an innovative way of commissioning.

2.2 *Testing and commissioning control systems with "Digital Water"*

The PLC is physically linked to a laptop, containing the simulation software WANDA. The numerical WANDA model feeds the PLC via an A/D converter. The PLC executes its algorithm and returns analog control outputs like pump speeds and valve positions. These analog signals are converted to digital values, which are returned to the WANDA model. WANDA gets these control outputs and continues the simulation in real-time mode with these control settings. The dataflow is outlined in Figure 1.

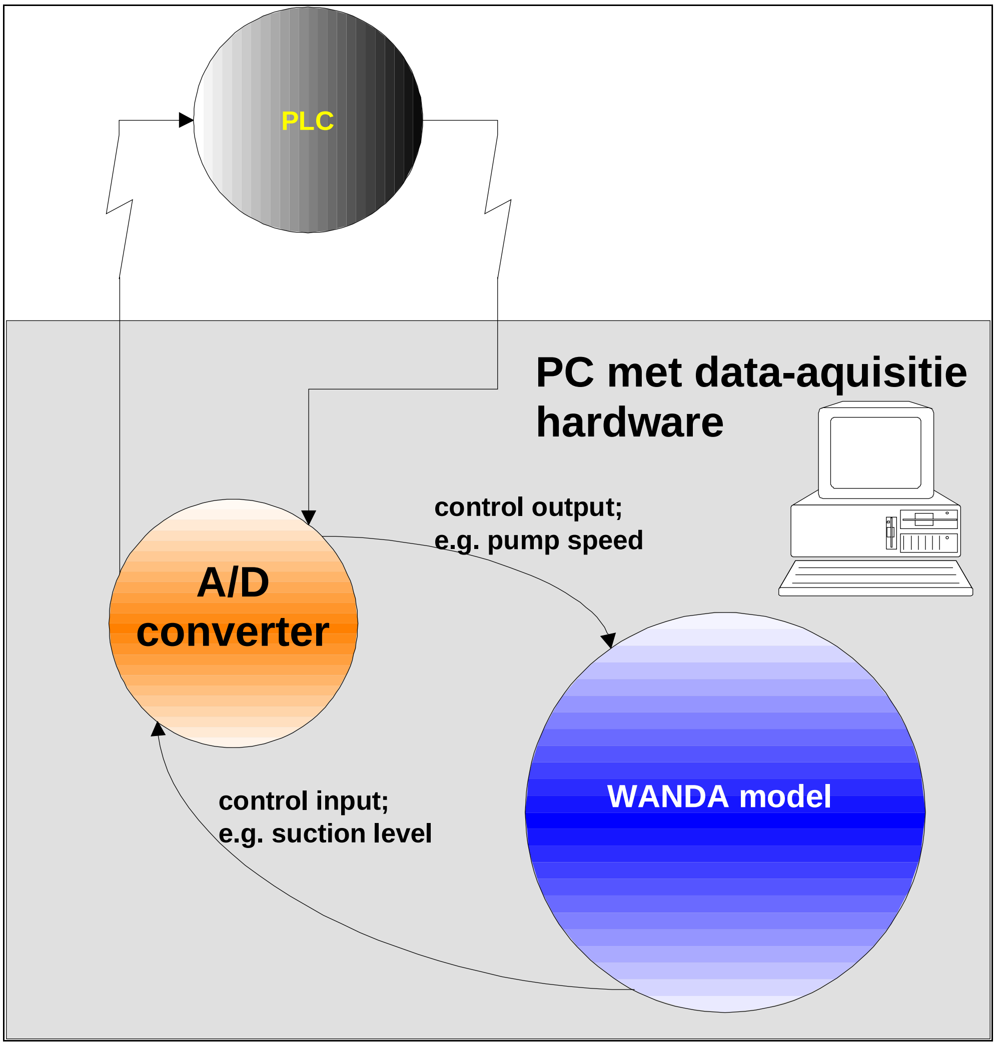

Figure 1: Data flow for Digital Water PLC testing

The computer simulates certain patterns of the supply to the pumping stations, which include normal daily patterns and extreme events like a heavy shower. These normal and emergency scenarios are selected in order to test the complete PLC behaviour of these booster stations and other large pumping stations. The numerical model is easily forced into any exceptional situation in order to test and verify the actual PLC behaviour over its full range of applicability. Furthermore, this test procedure is perfectly reproducible and harmless for the actual system. In this way, the PLC is tested with “Digital Water”. During testing the relevant signals are continuously displayed graphically in one or more charts to give the test engineers a direct feedback and full control of commissioning tests. This innovative approach for commissioning or testing of control systems has been successfully applied to sewage water pumping stations in Amsterdam and Rotterdam.

3 CASE STUDY: SEWAGE WATER PUMPING STATION IN AMSTERDAM

3.1 *Control philosophy*

This section summarises the experience gained during the tests of the PLC of pumping station “1st Weteringsplantsoen”, with 4 variable speed pumps and a total capacity of 6000 m^3/h, one of the largest sewage water pumping stations of Amsterdam. The control philosophy of this pumping station was as follows, prior to the test:

- If the suction level exceeds the ON-level during 30 seconds, the first pump starts.
- The running pump(s) aim for a certain target suction level with a Proportional-Integrator-Differentiator (PID) algorithm. Typically the D-contribution is marginal or switched off.
- If the pump speed remains at its maximum speed and the level does not drop to the target level within some pre-set stabilisation time, the next pump will start. Then the pump speed is temporarily reduced to create a smooth increase of the flow rate. After some stabilisation time the PLC picks up the current PID value for the pump speed.
- If the pump speed drops to a certain (minimum) speed and more than 1 pumps are in operation, then one pump will switch off.
- If the OFF-level is reached, the last pump will switch off.
- If a certain pump switches off at the OFF-level, then another pump should start first when the ON-level has been exceeded again.

Several scenarios have been prepared varying from continuous low flow supply (1000 m^3/h) to an increasing supply to 3000 m^3/h to the “1st Weteringsplantsoen” pumping station. The simulation model includes the network lay-out of the new upgraded system and realistic supplies to the other pumping stations with their designed control logics. The PLC of “1st Weteringsplantsoen” gets the simulated suction level and computes the number of pumps in operation and the pump speed. These results are returned to the WANDA model, which continues the simulation with these parameters and updates the suction level for the PLC of “1st Weteringsplantsoen”.

The “Digital Water” tests at “1st Weteringsplantsoen” took less than half a day only. The set-up is shown in Figure 2.

Figure 2: Overview of a set-up for a “Digital Water” test

3.2 *Test results*

The first pump started within a few seconds after exceeding the ON-level, neglecting the 30 s delay. Since the simulated supply increased rapidly to 3000 m^3/h, the first pump accelerated to the maximum speed of about 700 rpm within 30 s. Due to unknown fluctuations in the PLC output, the second pump does not start; see Figure 3. The suction level is about 80 cm above the target level in this period. After 8.5 minutes the second pump starts.

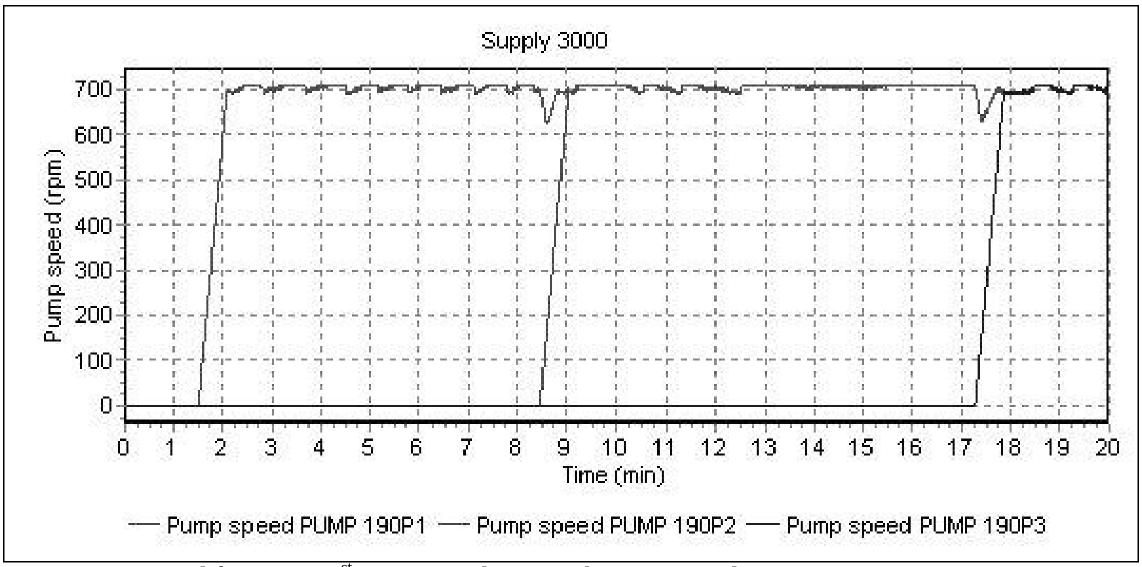

Figure 3: Pump speed from PLC 1st Weteringsplantsoen during “Digital Water” test

Since the PLC pump speed of the first pump immediately reduces from 700 rpm to 630 rpm, the discharge reduces by 30% from 2100 m^3/h to somewhat below 1500 m^3/h; see Figure 4.

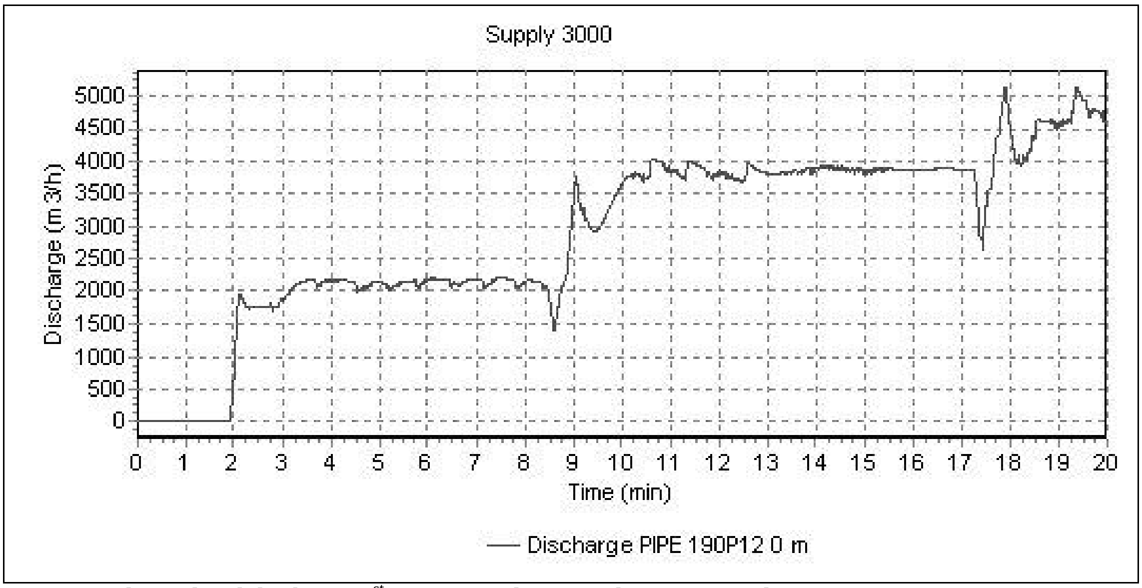

Figure 4: Total simulated discharge 1st Weteringsplantsoen during “Digital Water” test

Figure 3 shows that the first pump has returned to 700 rpm well before the second pump has gained this speed. It is clear from Figure 3 and Figure 4 that the first pump speed reduction occurs too early to realise a smooth increase in the total pumping station discharge. A similar 30% discharge reduction occurs on the start of the third pump.

The test with a continuous low supply from the sewers of 1000 m^3/h shows that the pump speed does not stabilise, nor do the fluid level and the flow rate (see Figure 5 and Figure 6). The target fluid level is -5.2 m NAP. Due to the 30 s delay on the start of the first pump, the suction level overshoots to -5.05 m NAP and the pump speed immediately overshoots to the maximum speed. After 3 minutes the level has dropped to the target level with a steep gradient. Nevertheless the pump speed gradually reduces to 480 rpm, while the suction level undershoots the target level. Apparently the PID settings can be improved such that the contribution of the differentiator increases compared to the contribution of the integrator.

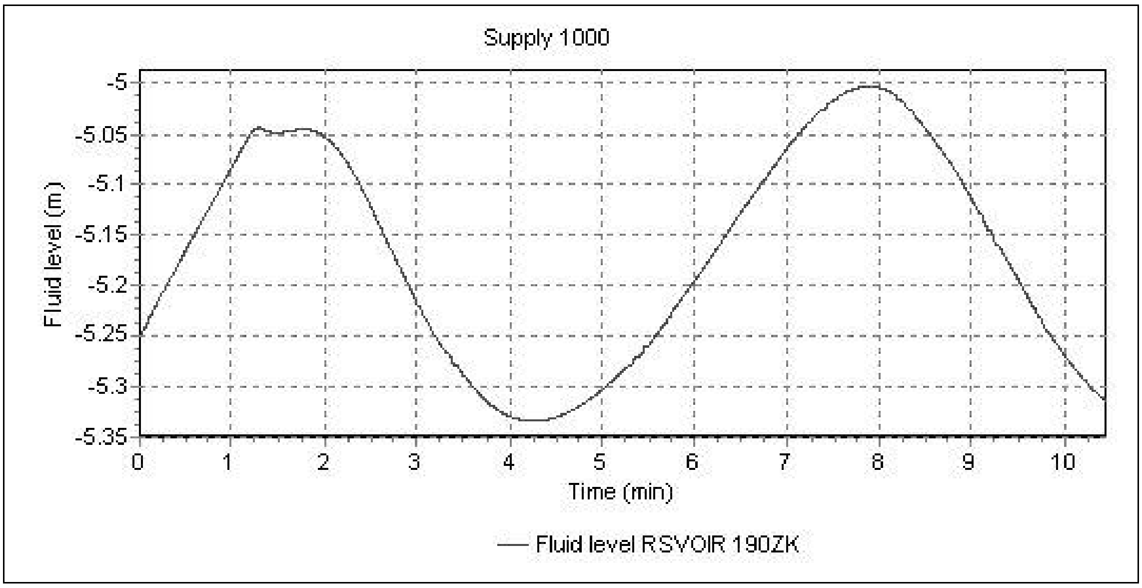

Figure 5: Simulated suction level during “Digital Water”test with low supply (1000 m^3/h)

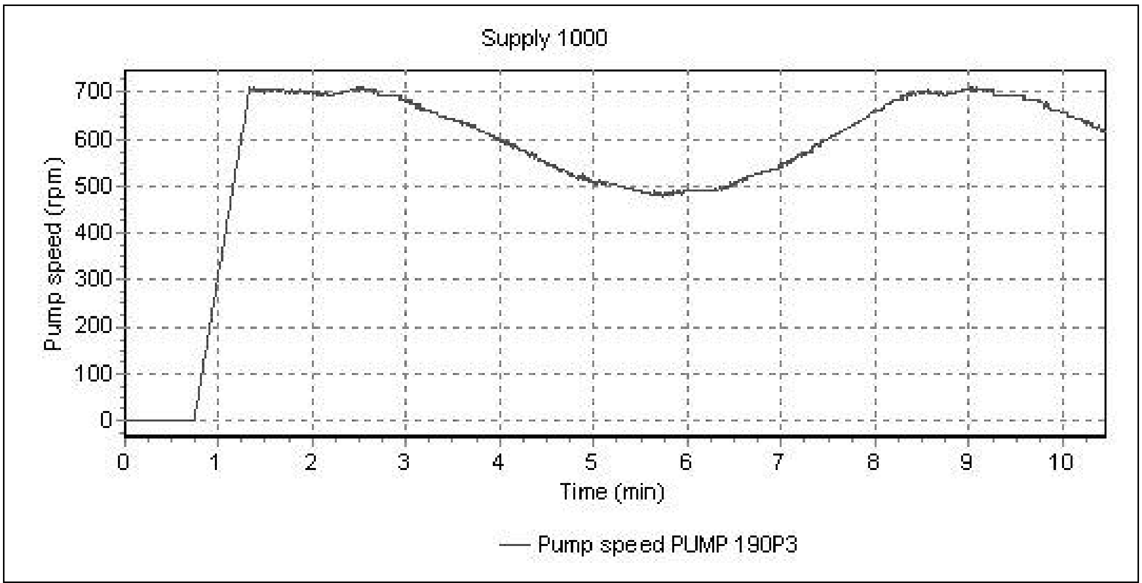

Figure 6: PLC pump speed during “Digital Water” test with low supply (1000 m^3/h)

3.3 *Conclusions of “Digital Water” test*

The “Digital Water” test at “1st Weteringsplantsoen” pumping station has revealed several improvements of the PLC. First, the temporary pump speed reduction during the start-up of the next pumps, aiming for a smooth discharge increase, has not the desired effect. It was recommended to remove this feature from the PLC. Secondly, the PID settings of the PLC should be improved in order to stabilise quicky to low flow supplies.

The “Digital Water”test has also shown the interaction between the nearest booster station and the actual PLC of pumping station “1st Weteringsplantsoen”. The test confirmed that the booster station control system has no negative effect on the behaviour of the pumping station PLC.

4 CONCLUSIONS

The direct graphical feed-back during a “Digital Water”test immediately reveals essential characteristics of a pumping station PLC and the interaction of this PLC with other pumping stations and the booster stations. The first tests, which have been conducted within one hour, revealed a few design deviations, which had not been identified during the Factory Acceptance Test (FAT). The “Digital Water”test enables to test extreme scenarios, which may occur once every ten years or less frequently. One of the main benefits of the “Digital Water”test is the reproducibility and traceability: exactly the same supply scenario can be repeated after proposed modifications to the PLC; this is impossible with the existing PLC-tuning practice. Another major benefit is the short test time. “Digital Water” tests significantly reduce the commissioning time of system upgrades and associated costs.

4.1 *Acknowledgements*

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5 REFERENCES

[1] Pothof, I.W.M., Feasibility of booster pumps in a wastewater transportation system: a case study, Conference Proceedings of 2nd Conference on Water and Wastewater Pumping Station Design, BHR Group, 2002 (p. 349-361).