**REPORT BY SCOTTISH WATER ON INTELLIGENT PUMP CONTROL TRIAL AT LEVENHALL SEWAGE PUMPING STATION**

*The following report by Graeme Moore, Senior Project Manager, Innovation & Technology for Scottish Water, details the pump blockage problems and their approach to its solution.*

Scottish Water recently identified that its Levenhall Sewage Pumping Station had significant issues with pump blockages and was considered the worst site for blockages in its south-east operating area. Often blockages and ragging needed to be dealt with two to three times each week. It was therefore an ideal site to try out a low-cost innovative solution for pump blockage detection and control, ‘Intelligent Pump Control (IPC) using an ‘off the shelf’ Control Techniques - Emerson variable-speed drive.

Pump blockages and rags are a significant barrier to realising energy and operational efficiencies in waste-water pumping throughout the world.

A number of new approaches to the problem of pump blockage detection and control have been developed in recent years and these are offering to improve reliability, whilst delivering improved efficiency.

**Background**

Pump blockage problems are a significant problem in Scottish Water; dealing with blocked pumps is a significant draw on operational time and resources. Implementing solutions at the most problematic sites would undoubtedly reduce call-outs, disruption, health & safety risks, travel time and both customer and environmental impact. The true scale of the problem is, however, unclear, as, often, the problem appears to be accepted as a routine maintenance task for some pumping stations.

**Pump Blockage Detection and Control**

A frequently occurring problem, with almost all types of impellers, is that fibres and other particles tend to build up on the impeller vanes. Generally, this build-up of rags causes a decrease in the pump’s hydraulic efficiency, increasing power consumption. This build-up of rags can then cause pump blockages if it continues to build up.

Pump blockages and rags are a significant barrier to realising energy and operational efficiencies in wastewater pumping. Further, an estimated three quarters of all pumps are over-sized[[1]](#footnote-1) by more than 20% to provide a ‘factor of safety’ in the design. The use of variable speed drives can be used to reduce the energy used by over-sized pumps, and reduce hydraulic system losses, but the increased frequency of pump blockages in wastewater pumping has always been an issue. Reliability is always more important than efficiency when it comes to meeting regulatory consents and delivering the high standard of service that our customers expect. Previously, the only solution to pump blockages was to try different types of sewage pumps. Pump designs to deal with rags has improved over the years, but no centrifugal pump currently on the market can be guaranteed to deal with all rags under all conditions, and increased frequency of blockage has been a persistent problem for pumps with variable speed drives, (VSDs).

The use of VSDs can play a substantial role in energy reduction by bringing the pump in line with the consented flow and reducing friction (energy) losses in the system. The ‘soft start’ functions can also increase the life of components, such as bearings and seals. There is significant value in energy savings and the resources associated with pump maintenance and repair. There are also the H&S issues that need to be managed every time a pump has to be lifted and maintained. It’s a dirty job and far from the ideal working environment, which requires a high degree of staff diligence.

Where VSDs are used, a small reduction in pump speed can reduce energy costs, especially where the system has significant friction losses. While process control and energy management are the two primary reasons for VSDs, there can be associated problems. A greater incidence of blockages at a wastewater pumping station can soon offset the energy-saving benefits associated with the VSD. Pump blockages can also result in premature spills/overflows, causing environmental issues with water courses, localised flooding and damage to our reputation, especially where blockages are regular and frequent. Because the increased risk of blockages can be a significant factor, when using VSDs for (unscreened) wastewater pumping, the ‘tried and tested’ fixed speed pumping solution has remained the favoured design approach over the years. Good design and pump selection generally ensures reliable operation with few blockages. Hence, blockage avoidance through a traditional design approach, and selection of blockage resistant pumps, has generally been considered to be more important than energy savings. Trouble-free operation is often seen to be more important than energy efficiency, as operating costs associated with problematic sites can often out-weigh what might be relatively marginal benefits on energy efficiency.

Some pumping systems, whether they are fixed speed or controlled by VSDs, can be prone to blockage simply due to poor hydraulic design, poor pump selection or an unmanageably high volume of rags in the system.

A number of new approaches to the problem of pump blockage detection and control have been developed in recent years and these are promising to put an end to frequent pump blockages, even at the most problematic sites.

At Scottish Water, we have tried PLC-based solutions, with success. However, this type of bespoke control package has to be provided over and above the VSDs, a costly solution that is only viable where it is not cost-effective to replace the drives.

One interesting alternative has been put forward by the VSD manufacturer Control Techniques – Emerson – their Intelligent Pump Control (IPC) software. This alternative solution is integral to the VSD, so doesn’t require any bespoke control package and can be provided as a standard VSD option. There is no additional cost to the purchase price of the VSD and its integral programmable controller. The Emerson VSD drive is also unique in that it monitors *active current* to determine variations in torque, which then triggers a reversing cycle to break up rags as they begin to form on the impeller. The active current monitoring allows very small changes in operating torque to be monitored. In short, the Emerson VSD solution appears to be a relatively low-cost solution to pump blockage detection and control. Furthermore, the VSD can be provided with a programmable module to integrate complex control logic into the VSD, so that separate programmable controllers are not required.

**Levenhall SPS – Trial site for VSD Blockage Detection and Control using Emerson VSDs**

Levenhall SPS is a low-lift station, part of the East Lothian coastal chain of pumping stations. The pumping station has a consented pump forward flow of 675l/s and an average static head of circa 7.2m. The rising main from the pumping station is circa 17.15m. Due to the short length of rising-main, none of the pumps have non-return valves and there is no interconnecting pipework between the discharge of the pumps, i.e. the pumps discharge individually into a gravity sewer, not into a rising-main.

The friction losses in the discharge of each pump are almost negligible, i.e. there is no real opportunity for efficiency gains through a reduction in hydraulic losses, through the use of VSDs. Therefore, all significant pumping inefficiencies can only be a direct result of blockages and ragging. This makes this an ideal pumping station to study the effects of ragging on pump efficiency, as normally VSDs are used to reduce hydraulic losses in the system. Since there are no significant hydraulic losses in the Levenhall system, energy gains can only be associated with better pumping efficiencies.

Levenhall SPS was identified as a site which is prone to pump blockages. Often blockages and partial blockages can occur two to three times each week, resulting in pump trips and operational call-outs. The problem subsides during dry spells, as the rags appear to be settling out in the catchment during periods of lower flow. However, there is no clear pattern of blockages and these can be equally frequent during dry or wet periods. A build-up of rags in the wet well is also a problem and these rags are often cleared manually, often once or twice a week, in an effort to reduce blockages. In short, Levenhall is a site which is very labour intensive and is a significant draw on operational resources. It’s not unusual for an operator to be on site dealing with ragging issues and problems every other day of the week with the pumps being lifted at least once a month.

When Levenhall SPS fails, the upstream pumping stations are inhibited and this results in a storm discharge at Prestonpans SPS, with the screened sewage being discharged into the Forth Estuary. A raw sewage discharge to the environment has issues for bathing water quality and for Scottish Water’s reputation.

Levenhall SPS has four foul pumps rated at 43kW each and three storm screw pumps. The screw pumps operate without any significant issues, are not a consideration in these trials.

Pump Motor FLC is circa 70 Amps per phase and at the theoretical pump duty point the pump motors *should* operate at circa 35 Amps per phase.

Levenhall uses circ £28k per annum of electricity and requires circa £15k per annum of operational interventions, to deal with ragging, blockages and pump trips, but there are additional hidden costs, such as the knock-on effects due to resources being diverted to deal with problems at Levenhall SPS.

Operations have been considering changing the pumps, due to the ongoing blockage problems, and have trialled an alternative pump, but even this alternative pump experienced blockages. All the existing pumps are generally in good working order, and had recently been refurbished. Replacement pumps, which might be another solution to the problem were estimated at £120k to £140k, compared to the drives which were around £7k each.

The pilot project initially saw the installation of a single VSD on one of the existing pumps (Pump No 1), to investigate if the energy usage and the occurrence of blockages on that pump could be significantly reduced. Improving efficiency and reducing the frequency of blockages and partial blockage is the aim of the pilot project. The hydraulics of the system doesn’t offer any real opportunity for energy savings through reduced hydraulic losses. However, energy savings are expected to materialise if the pump can be kept free of ragging on the impeller of the pump.

The inability of the existing pumps to deal with high levels of ragging might be a significant part of the problem, although an alternative pump still continued to have blockage problems, so there was a significant risk that the blockage problem would continue even with alternative pumps. However, if the solution can be demonstrated to work on a site where the problem is considered very challenging, it will demonstrate that the technique can be used to defer capital expenditure and realise Opex efficiencies where blockage is a significant problem, even where the pump has an inherent inability to deal with the rags.

The Levenhall SPS trials started on the 10th June 2010, with a single VSD installed on Pump No 1.

**The trial**

The pump blockage detection and control trial at Levenhall SPS seeks to prove that pump blockages can be significantly reduced and the pumps can operate more efficiently as a result.

Since the trial started, results are proving that pumping efficiency has been seen to improve by up to 15%. Other Opex associated with blockages will reduce Opex by up to £15k per annum. However this doesn’t include Opex associated with the knock-on effects of problems at the site, e.g. overtime to maintain scheduled work and routines impacted by problems at Levenhall.

Pump motor trips due to pump blockages have also been reduced from two to three each week to none at all reported in the last month of operation. No crane hires have been required to remove any pump with the pump blockage detection and control system since the trial began.

Rag balling in the wet well and the need for manual intervention to remove rag balls and partial chokes have been significantly reduced, with no reported blockages since all drives were put into operation, giving at least two months of trouble-free operation at Levenhall.

The Levenhall trial proves that pump blockage detection and control is achievable using Emerson’s Control Techniques drives. Regular pump blockages at the station should now become a thing of the past and the pumps should operate more efficiently as a result.

The long-term performance of the station and the long-term success of the trial will be monitored by Scottish Water Operations. However, this is expected simply to validate the results to date which can be maintained over the long-term.

The team leader indicates that there has been a noticeable reduction in overtime; staff are now better able to keep on top of routine activities without being diverted to deal with persistent blockages and rag balling problems at Levenhall. It was also noted that staff were able to help the local wastewater treatment operatives to deal with issues associated with recent severe winter weather, which would not have previously been possible if Levenhall had still required the same level of manual intervention to deal with blockages and associated issues.

**Impact Summary**

***Opex***

Energy - £4.2k per annum

Pump Maintenance - £15k annum

**Capex**

Pump replacement capex savings - £150k

Investment for four new 45kW drives £39k

**Trial Results**

**Week 12 June 2010**

The following is based on a week of operation, so can not be considered conclusive:

On the 12th of June all the pumps in the station, *with the exception of Pump No1* with the VSD with the IPC system, had become blocked and had to be lifted to clear blockages. On the 16th of June pump No 2 and No3 were again blocked or partially blocked and *Pump No 1 was clear of blockages.* Pump No 4 was not inspected.

The average running current of Pump No 1 has been between 15 to 30% less than pumps 2, 3 and 4 since the VSD was installed. Some minor teething problems with VSD parameter settings resulted in premature tripping, which was quickly resolved.

Inspection of pump impellers reveals cavitation damage on the surface of pump No 2 impeller, due to blockages. Cavitation results in premature impeller wear and shorter impeller life. Davy Campbell, the site operator, knows that the ‘rumbling’ noise of cavitation is a sure indication that the pumps are blocked and can take action to resolve the problem…but, believe me, that’s not a job for the faint hearted.

Due to the short length of rising main, none of the pumps have non-return valves, so a blockage in one pump can be flushed back into the wet well, when the pump stops or trips. It was noted that these ‘blockages’, which can form in one pump, can be set free in the wet well and can be sucked into the other pumps. The ‘rag balls’ are a tightly packed bundle of rags, that exceed the maximum diameter of solids that can be handled by the pumps. So, if these rag ball are sucked into a pump, the pump is unable to deal with it, and is likely to trip.

**Month July 2010**

The first month of operation proved to be relatively successful in proving that the pump inlet remains free of ragging during daily operation; however the number of pump trips in pumps 2, 3 and 4 due to rag balls has remained an issue. Rag balls are still being removed for the wet well 2 or 3 times a week. Although, ragging in the suction of pumps 2, 3 and 4 has been reported, there was one reported choke in the suction of pump 1 – this appears to have occurred when pumps 2, 3 and 4 had also tripped.

Patterns of tripping and blockages from the operational log are not particularly clear – however the number of manual interventions, due to rag balls appears similar to previous months.

A log of operating currents as shown in figure 1 below clearly indicates that Pump No 1 is operating at much lower average running currents than the other drives. This indicates that the Pump No 1 is able to operate much more efficiently than pumps, 2, 3 and 4.

Note - The bar chart shows running currents each time a pump operates and this is not related to the sequence of pump operation. The pumps cycle duty1/duty2/duty3/standby, so only three pumps operate simultaneously during a pumping sequence.



Very high peak currents at starting are also an indication that a blockage has formed. Cycles where high peak currents occurred are not included in the above operating cycles, as these skew the results on the high side. However, these spikes on starting currents appear to be regular occurrences. Up to 1 in 6 operating cycles will see very high peak currents. The highest recorded peak currents for each pump are recorded below. These high operating currents often result in pump trips. Note pump one has the VSD, and high starting currents are no longer seen on this drive.



The average running current and peak operating currents for Pump No 1 have been seen to be significantly reduced and this has a significant impact on the operating efficiency of the pump. Running currents can be up to 40% more on the pumps that do not have any blockage detection and control associated with the pump, although operating currents between 10 and 25% more is typical. From the available data, it appears that the average energy consumption at the site could be reduced by up to 15% per annum, if all pumps had Control Techniques Emerson drives with the IPC system fitted.

An issue of rag balling was further highlighted by the operator. The compacted rag balls that are being observed at Levenhall can be up to 600mm in diameter (with some reported as bigger than this), see figure 1. These are too big for any pump to deal with and are thought to be too compacted to be broken up by the anti ragging technique. A compacted rag ball of this size results in a pump blockage, or trip, when it is pulled into the pump suction. The continued formation of these large compacted rag balls remains a significant problem. There is a belief that these rag balls are being formed in the suction of the uncontrolled pumps, as described earlier, but it remains unclear, at this stage, if this is in fact the case.



Fig 2 Typical Rag Ball – removed from pump.

**Month August 2010**

A second VSD was installed on pump 2, to check that the impact on pump operating efficiency could be repeated on that pump. As can be seen in figure 3 below, the change in running current is quite significant for pump No 2. From previous results during the first month of the trial pump No 2 could be considered to be the least efficient pump.



Figure 3 – Typical Operating Currents

However, rag balling in the wet well remains a significant issue which continues to result in pump trips and blockages in pumps 3 and 4. Reported trips on pump no 2 were revealed to be associated with the pump protection relay and not the VSD, there was only one incident of the VSD tripping, due to an overload, probably associated with a rag ball. However, this spurious tripping was not logged by the VSD, so it was clearly not a problem associated with the VSD, but with the pump protection relays. Operations were asked to check the pump protection relay and the seal leak to ensure that this device was functioning correctly. Pump No 1 has not had any issues with the number of trips, only two have been reported, since the VSD was installed, and the pump has not been reported as blocked or choked.

Investigation into the frequent tripping of pump number 2 revealed a faulty relay.

Emerson highlighted that rag balling from uncontrolled pumps could be a risk at the onset of the trials, as they had had similar experiences on other sites with mixed controlled and uncontrolled pumps.

**Early Conclusions (based on 2 pumps out of four using VSDs with blockage detection and control)**

Ragging at Levenhall continues to be a significant problem, resulting in high energy costs and excessive manual interventions to keep the station operational.

Pump No 2 reported a high incidence of trips, but this is not associated with the VSD or the anti ragging technique.

Pump No 1 and No2 have been provided with an Emerson 'Control Techniques' VSD with IPC to detect a build up of rags and take action to break up the rag through a process of reversing cycles. The average running current and peak operating currents for Pumps 1 & 2 have been significantly reduced indicating a significant impact on the operating efficiency of the pump. The average running currents over a day’s operation can be between 15% and 25% more than for pumps which do not have the VSDs for blockage detection and control. Analysis of average operating currents reveals that the average energy consumption at the site could be reduced by up to 15% per annum, if all pumps had the IPC system fitted.

A problem with rag balling continues to be an issue. Unless all pumps are fitted with VSDs for blockage detection and control, we are unable to conclude at this stage that the technique is effective, as we believe the formation of rag balls to be associated with the uncontrolled pumps could cause the controlled pumps to trip if the rag ball is drawn into the suction of the pump. As, previously mentioned, spurious tripping, due to a faulty pump protection relay, made it difficult to draw clear and unambiguous conclusions about the formation and impact of rag balls on the pumps.

**October 2010**

VSD’s were installed on the remaining two pumps, Pump Nos 3 and 4. It was agreed with operations that this was the only reliable way to determine if the rag balling in the wet wells could be managed or prevented from forming.

Within the first week of operation, the rag balling and pump blockages were as bad as they had been at the start of the project, with all pumps blocked or partially blocked and significant rag balls forming in the wet well and running currents on all pumps were significantly higher than expected. An investigation into the problem revealed that the blockage detection and control features of the VSD’s had been disabled and the pumps were not going into their cleaning cycles when a blockage developed. This was a significant inconvenience to Scottish Water as a crane had to be hired allow the pumps to be unchoked. However it served to emphasise just how effective the Emerson equipment had been when operating to control blockages.

The blockage detection and control was enabled on all four drives, week commencing 25th October 2010. The pump blockages stopped immediately on enabling the blockage detection and control, the rag balling issues in the wet well appeared to decline over the first week of operation and running currents on all drives returned to lower values previously observed, between 38 and 43 amps approximately.

Rag balling in the well during the first two weeks of November has seen a significant decline, operational reports indicating a significant change in the number of rag balls evident in the wet well. Early indications suggests that rag balls are either no longer forming in the wet well, or the cleaning cycle is breaking up rag balls, which flow into the wet well, to allow rags to be pumped forward without blocking the pumps. Operations believes that the rag material is being transported forwards before it gets a chance to form larger rag balls in the wet well.

**Final Conclusions**

The Emerson Control Techniques drives can be used to provide effective blockage detection and control.

Where pumps are operating significantly above their theoretical running currents due to pump ragging and blockage, pump blockage detection and control techniques can be utilised to reduce running to nearer the theoretical value.

It would not have been possible to understand the link between energy efficiency and pump performance if data on running currents were not logged at Levenhall. It is clear from this trial that we are missing significant opportunities to assess pump performance, and deliver efficiencies because most sites do not log sufficient performance data, e.g. running currents, flow and specific energy.

It isn’t possible simply to compare individual pump performance without individually monitoring the pumped flow and kWhrs to provide data on specific energy. More data is required fully to compare pump performance and select which pump or combination of pumps is most efficient for all pumping regimes. A more detailed assessment of energy consumption is not possible without flow data, but the reduction in running current is a clear indication that the pumps operate more efficiently under a regime of blockage detection and control. Data on pump performance is essential if energy efficiency is to be managed effectively.

Generally, VSDs can also be used further to reduce hydraulic losses in the system. However, hydraulic losses at Levenhall were not sufficiently significant to change the pump control philosophy.

A phased approach to installing VSDs for pump blockage detection made it difficult to conclude that blockage detection and control was possible, as rag ball in the wet well continued to be a significant problem. Had all VSDs been installed simultaneously, a return on investment could have been realised within two years. The phased approach resulted in an ROI estimate of three years, assuming interventions are reduced by 90% and energy consumption by up to 15%. However a return on investment is available without taking account of energy savings.

**Recommendation**

Variable speed drives with blockage detection and control should be used to reduce operational interventions where blockages and ragging problems exist or where there is a high risk of blockage, e.g. down-stream of CSO’s, where rags are returned to the system during a storm event for onward pumping.

All VSD’s used for raw sewage pumping should be specified to have pump blockage detection and control as standard.

All sites with significant pump blockage problems should, wherever possible, be provided with VSD’s with pump blockage detection and control, where a reasonable ROI can be calculated. A list of pumping stations with blockage problems should be created and prioritised for capital investment. Prioritisation criteria needs to be agreed, but Opex intervention and energy costs are probably key criteria for prioritisation.

All new pumps should be reversible, to allow pump blockage detection and control techniques to be applied.

VSDs with pump blockage detection and control should be considered as standard for all half hourly meter pumping stations, or all stations which require starting currents to be controlled, e.g. typically pumps above 7.5 kW.

If pro-active maintenance regimes are to be achieved, it is strongly suggested that all half-hourly metered site have better energy and performance monitoring, alarms and controls.

The amount of data on pump performance and energy consumption needs to be reviewed if pro-active maintenance regimes are to be successful. We were lucky that running currents were logged at Levenhall, or the impact on energy may have gone unreported. A minimum data set, over and above current telemetry requirements should be a serious consideration. A suggested data set is as follows, available for chronological data logging, especially for half-hourly metered pumping stations:

***Per Pump***

Running current (all phases)

kWhrs

Specific energy eg l/kWhr or m3/kWhr

Individual trip condition monitoring

Forward and Reverse direction of rotation

Cumulative count of cleaning/reversing cycles

***Per Station***

Pumped flow (calculated from wet well rate of change or via mag flow)

**Personal Thanks**

Many thanks to Chris Turton and Davy Campbell of Scottish Water Customer Services. This project could not have delivered the benefits without their support and seeing the potential of an innovative solution.

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1. British Pump Manufacturers Association [↑](#footnote-ref-1)