EXPERIENCES WITH SHUTDOWN AND PIT STOP MAINTENANCE IN HYDROPOWER PLANTS

Short content:

- Introduction to shutdown and pit stop maintenance
- Examples and case studies on shutdown and pit stop maintenance in hydropower plants
- Pit stop maintenance - A method for making maintenance more efficient

Key learning points:

- Challenges concerning shutdown and pit stop maintenance in hydropower plants
- Application of shutdown and pit stop maintenance in hydropower plants
- Benefits and pitfalls

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Abstract: *This paper reports experiences with shutdown maintenance in hydropower plants. Shutdown maintenance requires the generating unit of a hydropower plant to be stopped for a period of time for maintenance purposes. These shut downs may lead to water losses and decreased availability. Outage time and water losses cause financial losses because less power can be produced and sold on the market. The size of these financial losses can be up to 100 000 EUR/day for a run-of-river power station. This motivates a minimisation of the outage time by reducing the time spent on each maintenance activity through elimination of unnecessary activities as well as an optimisation of the shutdown maintenance frequency. The motivation for efficiency improvement of shutdown maintenance forms the basis for future pit stop maintenance in the sector. Pit stop maintenance involves the same maintenance activities as shutdown maintenance, but more thorough preparations and plans are made before stopping the unit in order to reduce the outage time. The activities during the shutdown are monitored closely and subsequently evaluated with the intention to identify activities which can be improved, hence achieving continuous improvement. Training and education are essential success criteria for pit stop maintenance. Examples of potential for pit stop maintenance in hydropower plants are also described in this paper.*

1. Introduction

1.1 Shutdown maintenance

A shutdown is defined as an outage scheduled in advance, for maintenance or other purposes [1]. These other purposes may involve activities like modifications or new installations of equipment [2]; see Fig. 1.

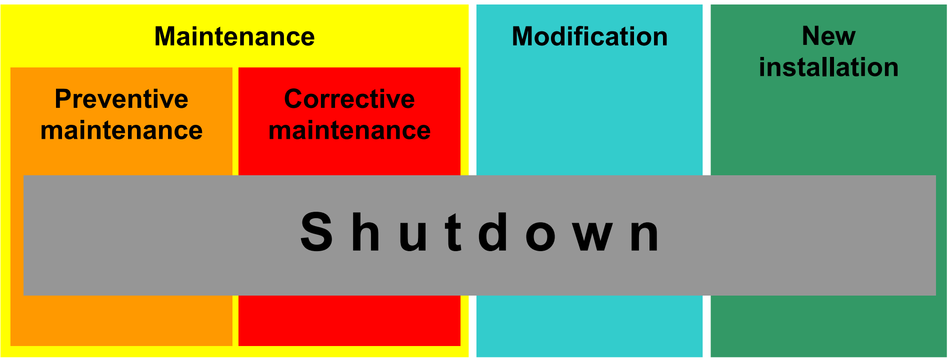

Fig. 1. Activities performed during shutdown.

Some of these activities do not require a shutdown of the generating unit since they can be carried out when the unit is operating. However, the focus in this paper is on shutdown maintenance, that is, maintenance that can only be performed while equipment is shutdown. A shutdown may have different durations; both short stops, involving for instance preventive maintenance tasks, and longer stops for installations of new equipment.

The work load of the maintenance department depends on the kind of maintenance performed as illustrated in Fig. 2. The everyday maintenance activities are distributed and given a constant level of activity. Shutdown maintenance causes a sharp increase in the workload of the maintenance department. This is illustrated by peaks in the workload in Fig. 2 and implies stress on the workforce and may imply a need for contract workers. Prior to the actual shut down, preparations and planning are carried out, and evaluations are performed after the shut down.

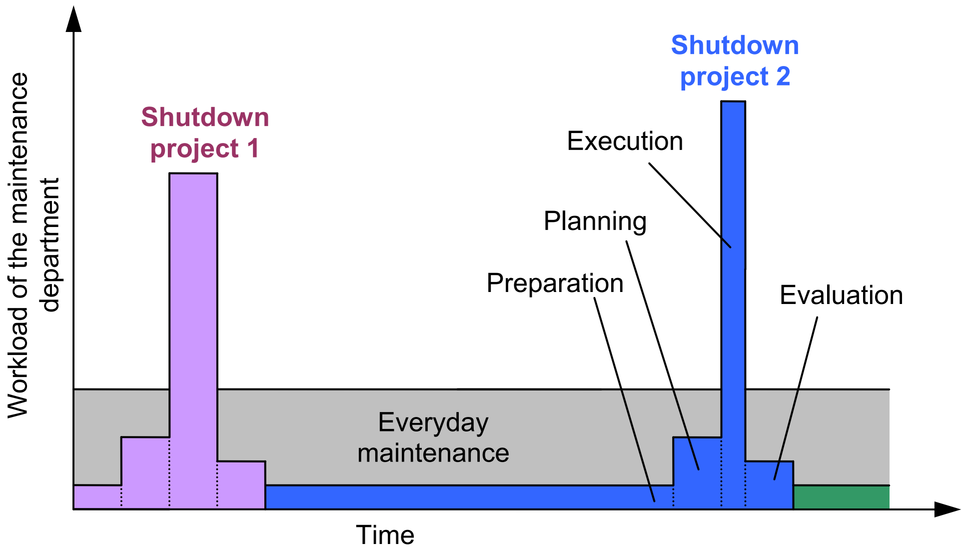

Fig. 2. Workload of the maintenance department (adapted from [2]).

A survey performed in 1998 [2] indicated that Norwegian companies had a large potential for improving their shutdown maintenance. The following observations were reported:

- Poor strategy development for the shutdown maintenance.
- Objectives for the shutdown were not defined, which means that the shutdown did not fulfill the needs and requirements for the shutdown.
- The intervals between the shutdowns were not optimal.
- Inadequate planning, control and follow-up of the shutdown maintenance.
- Project management tools were seldom used.
- Poor organisation and description of responsibilities.
- Lack of resources when unexpected events occurred.
- Inefficiency when performing shutdown maintenance.

Another survey performed in 2002 [3] showed that less than half (44 %) of Norwegian companies plan their maintenance activities.

1.2 From shutdown maintenance to pit stop maintenance

The above mentioned surveys illustrate the need for a new concept for shutdown maintenance. Therefore, the concept pit stop maintenance has been introduced. The term pit stop is borrowed from Formula 1.

In Formula 1, stops have to be made in order to change tyres, refill fuel, etc (Fig. 3). Seconds divide winners and losers and therefore the stops are optimised and the activities limited to the most necessary tasks. Keywords to success in Formula 1 pit stops are:

- Team work
- Defined tasks and responsibilities
- Communication
- Condition monitoring
- Continuous improvement
- Technological/design optimisation
- Benchmarking
- Training and practice.

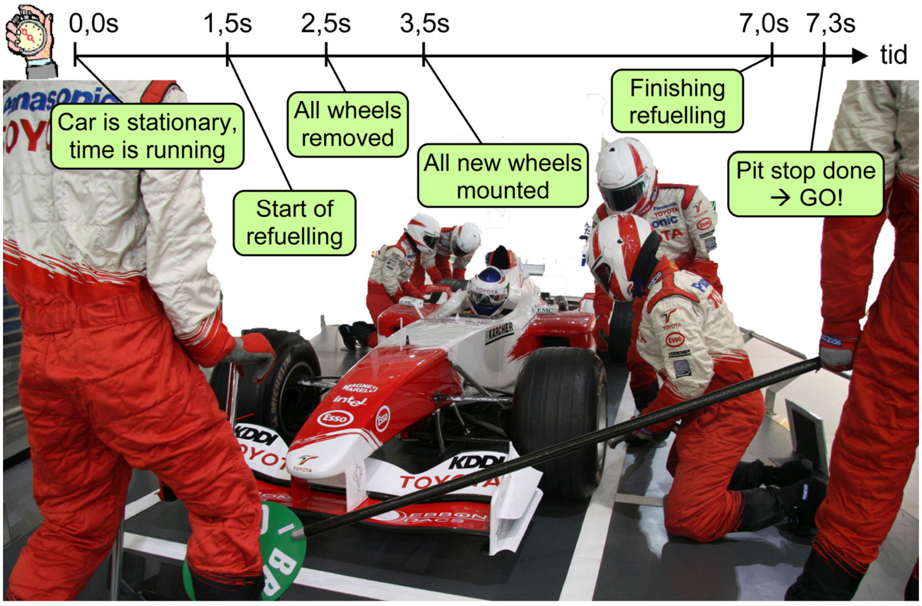

Fig. 3. Pit stop in Formula 1.

Pit stop maintenance is concerned with making the currently performed maintenance actions more efficient, hence saving both time and money. This implies a stronger focus on preparation, planning, follow-up and evaluation than during shutdown maintenance. Pit stop maintenance is based on theory from shutdown maintenance and project management. Including elements from Formula 1 will increase the focus on speed and control of the maintenance activities. These points are essential in pit stop maintenance. However, it will also be necessary to deploy theory from logistics, organisation, management and resource planning. The 5S-concept is a premise for successful pit stop maintenance. Safety is also important, but the focus on speed must not endanger the working conditions of the personnel.

It is important to have objectives for pit stop maintenance. These objectives can be used to manage and measure a stop. There are two main types of objectives: strategic objectives and performance objectives. Strategic objectives specify what the company wishes to accomplish with the pit stop maintenance concept. Typical examples are increasing the availability of a machine by *x* % or reducing the need for corrective maintenance by *y* %. Performance objectives apply for a specific pit stop and specify the objectives for the actual stop such as completing the stop on less than *x* days or the cost must not exceed *y* EUR [2]. The objectives make it easier to measure goal achievement through the use of KPIs and the success/failure of the pit stop maintenance.

2. Shutdown maintenance in hydropower plants

In this chapter, experiences with shutdown maintenance in hydropower plants are reported. First, the work flow of the shutdown maintenance is presented and then a short description of the two case studies is given. Finally, some of the challenges of shutdown maintenance in hydropower plants are summarised.

2.1 Work flow

Two case studies involving shutdown maintenance have been performed in close cooperation with two Norwegian hydropower companies, Akershus Kraft and EB Kraftproduksjon. These shutdowns involve mostly preventive maintenance activities requiring the generating unit to be stopped. Examples of activities are inspection of stator, cleaning of transformer, function tests of protection and control systems etc. The objective for the case study was to come up with suggestions for improvements, hence trying to move towards pit stop maintenance. The work flow is similar for the two companies and is illustrated in Fig. 4:

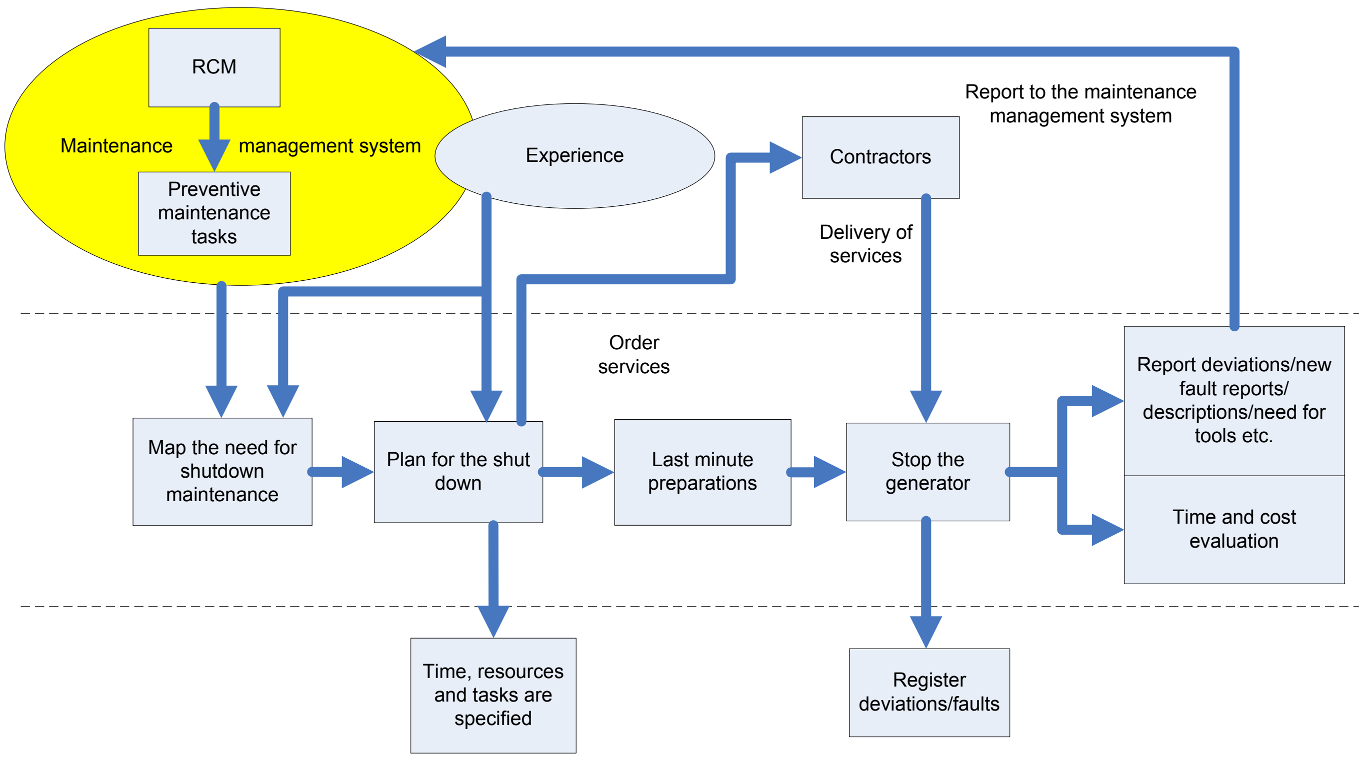

Fig. 4. Work flow for shutdown maintenance.

The following list explains some of the key elements of Fig. 4.

- The yellow ellipse in the top left corner illustrates the maintenance management system. Results from RCM analyses [4] [5] [6] are available in the maintenance management system as descriptions of preventive maintenance activities to be performed during the shutdown.
- Maintenance activities combined with experience of the maintenance personnel is used to map the need for shutdown maintenance.
- Both experience and earlier practices are important when making a plan for the shutdown maintenance. Timing, duration, resources and activities to be performed during the shutdown are specified in this plan. In addition, orders for services from contractors are made.
- The last minute preparations involve deciding who will be responsible for which tasks and discussing safety routines and checking tools/equipment etc.
- During the shutdown of the generating unit, preventive maintenance activities are performed according to the plan and services are delivered from contractors. While the work is performed, notes are made about deviations and faults.
- After the shutdown it is important that deviations, new fault reports and improved work descriptions are entered into the maintenance management system. This will ensure that valuable experience survives until the next shutdown maintenance is performed. Time and cost evaluations are also part of the follow-up.

2.2 Case studies

The case study at EB Kraftproduksjon concerned a 30 MW generating unit from 1995. EB Kraftproduksjon has made a package of 10-15 work orders to be used for all their run-of-river power stations. The work orders are basically the same for all units, however adjustments are made for special equipment or conditions for the individual unit. Work orders which can be performed while the unit is running are not included in the shutdown maintenance. All shutdowns are planned to take 7.5 hours. There was no loss of water for this particular shutdown due to the fact that a backup generating unit, usually used in case of inundation, was used instead of the generating unit that was stopped. Nevertheless, the shutdown reduced the availability of the unit. During the work with this case, changes in the work orders were suggested to reduce the outage time; for example more condition based maintenance should be performed. It might not be necessary to clean transformers and other components every year, every second year might be enough if reviewing the need for cleaning first.

In the second case study performed at Akershus Kraft, shutdown maintenance on a 44 MW generating unit from 1983 was studied. In the case considered here, Akershus Kraft had to send parts of the generating unit to a repair shop. This resulted in a longer stop than usual. A Gantt diagram was prepared for the shutdown showing the different tasks, and the duration and schedule of the activities. During the shutdown the work orders to be performed were stuck on a wall. After an activity had been performed it was crossed out so that the work progress was visible for the involved personnel. When the shut down was completed, the work orders were handed out to the maintenance personnel. This was done so that the personnel could mark down suggestions, improve work descriptions etc. During this particular shutdown, it was possible to bypass the water through an older station. Water loss was avoided, but the old station had lower efficiency. The estimated loss in efficiency was, in monetary terms, 1 300 EUR per day.

2.3 Challenges

There is a potential for improvements of the shutdown maintenance, despite refinements made during the last few years. Further improvements will be a step in the direction towards pit stop maintenance. The evaluation process of shutdowns, especially transferring new knowledge to the next shut down, can be made more efficient. Hence, focus on continuous improvement is required. The interval of the shutdowns can also be optimised, since both companies currently perform shutdowns once every year and this might not be necessary. An important challenge is training, since some of the maintenance tasks are performed quite rarely. Yet another challenge is the use of contractors. At the moment the contractor market in Norway is quite overheated and it can be hard to get contractors when needed. It can also happen that the contractors dictate the length of the shut down due to their heavy workload. Some have suggested that in-house competence might be the answer to this problem, or better buyer competence in the companies.

3. Pit stop maintenance in hydropower plants

Shutdown maintenance and pit stop maintenance often involves the same activities, but pit stop maintenance implies an increased focus on preparation, planning, execution and evaluation and defining objectives for the shut down. This chapter describes possibilities for pit stop maintenance in hydropower plants. The focus is on activities with longer duration compared with the activities in the case studies described in Chapter 2.

3.1 Work flow

Pit stop maintenance in hydropower plants has four phases (Fig. 5) and each of them may contain a number of different activities.

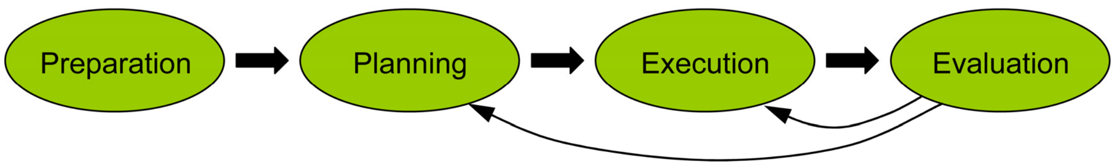

Fig. 5. Pit stop phases.

The main objectives of the *preparation phase* are to determine the detailed scope of the pit stop, perform the overall project planning, engineering, procurement and manufacturing activities. The following issues should be carefully considered during this phase:

- The exact condition of the machinery should be known to the extent possible. This is to avoid surprises after dismantling that may jeopardize the pit stop time schedule.
- The final scope of the pit stop should not only be determined on the basis of the condition of the machinery, but may also be influenced by strategic decisions. One may detect larger modules with an easy and “quick” interface towards the remaining parts of the machine that will allow a fast replacement of the parts in question. For example, instead of replacing only the stator bars one may choose to replace the complete stator, since this work can be performed much more rapidly.
- Engineering, procurement and manufacturing activities should all be completed well in advance of the actual pit stop.

The *planning phase* contains the detailed planning of the pit stop. The schedule should describe the activities on an hourly basis. The following issues are important and should be carefully considered:

- All activities not requiring a stop should be removed from the pit stop. Additional tasks could be included provided that a stop at a later stage can be avoided.

- As many activities as possible should be carried out in parallel. Bottle necks should be resolved, and activities on critical line should be made efficient, e.g. by introduction of special tools.
- Both day and night shifts should be introduced.
- On-site manufacturing by use of mobile equipment and tools should be used in order to avoid shipment to and from workshop. On site manufacturing will also contribute to maintain the “push and pull” to get the job done.
- A pit stop team leader that is good at organising, well structured and foresighted should be chosen.
- A pit stop team should be organised. Only the most efficient and competent personnel should be selected for the pit stop, and the personnel should be trained. The team should also have dedicated expeditors whose responsibility is to assist in the on-going activities, but even more to prepare resources, drawings, materials and tools for the next activities.
- It is important to set up communication lines to technical expertise that will provide for a quick resolution to technical problems not foreseen.
- Incentives may be introduced, like bonuses.
- Work processes for the various pit stop tasks should be established.

The *execution phase* contains the on-site preparations, the pit stop itself, de-briefing and de-mobilisation. Prior to stopping the unit all necessary materials must be available, checked and in perfect condition. All tools must be in place and working. It is also important that the personnel have understood the responsibilities they have, and which tasks they are going to perform. The following issues are important during the actual pit stop:
- All materials and tools should be available, tested and counted before the machine is stopped.
- Back-up of critical resources should be established.
- Caring and treatment of the personnel should be kept at a reasonably good level.
- Briefing and de-briefing at start and end of each shift. All procedures should be well understood and responsibilities defined.
- Inspection and testing of the work should be performed continuously, and not only after completion of a set of tasks, thereby be able to detect and correct errors at the earliest stage possible.

The *evaluation phase* is performed after de-mobilisation and should aim at improving the pit stop maintenance performance next time. The processes and procedures should be updated and reflect the experiences made. This is illustrated by the arrows from the evaluation phase to the planning and execution phases in Fig. 5. Benchmarking towards similar processes in other businesses may also contribute.

3.2 Relevant cases

Three cases have been analysed and planned in order to demonstrate the potential reduction in outage time if implementing pit stop maintenance. These are:

1. Replacement of stator winding
2. Re-insulation of pole cores
3. Re-insulation of pole cores and field windings

<u>Replacement of stator winding</u>
The normal outage if a stator winding needs to be replaced is from 90 to 110 days, depending on the size and type of machine. A complete replacement of the stator instead requires just 21 days. If implementing pit stop maintenance the stop can be further reduced to 12 days according to the estimations made.

<u>Re-insulation of pole cores</u>
The traditional way of doing this is to disassemble the poles, ship the poles to a workshop for re-insulation, and then assemble them. The outage can be from 50 to 60 days. If implementing re-insulation facilities on-site, the disassembling, re-insulation and assembling activities can run in parallel and if in addition applying other aspects of pit stop maintenance the outage can be reduced to approx. 15 days.

<u>Re-insulation of pole cores and field windings</u>
If replacing the poles with new poles instead of shipping the poles to a workshop for re-insulation, and in addition applying pit stop maintenance methodology, the outage can be reduced substantially from approx. 90 days to 5 days.

Fig. 6 shows the pit for the generating unit in hydropower plants.

Fig. 6. Generating unit pit.

3.3 Challenges

The most challenging part of a pit stop is to achieve the maximum performance of the pit stop team. The two most critical drivers are 1) planning of the pit stop and 2) the organization of the pit stop team itself. Without focus on these two important drivers, the pit stop method will fail. Furthermore, a pit stop will never be successful the first time it is performed. But by practicing and continuous improvements the pit stop team will gain experience and start functioning well together and subsequently succeed in reducing the outage time.

4. Development of maintenance best practices methods

Effective shutdown and pit stop maintenance methods in hydropower plants are important focus areas in the R&D project *Value adding maintenance in power production*. The five year project (2006-2010) is carried out at SINTEF Energy Research in close co-operation with Norwegian and Swedish hydropower companies and service providers. The three main parts of the project are:

- Best practice maintenance - Establishing best practice maintenance for hydropower production.
- Life curves for maintenance optimisation - A life curve indicates the degradation from commissioning to failure and can be used as input for models for scheduling and optimisation of maintenance [7].
- Maintenance towards 2030 - Identifying scenarios for maintenance towards 2030. Based on these scenarios the need for new products, solutions and knowledge to meet new challenges will be identified.

The main objective of the project is to develop and test maintenance best practices methods, criteria, software tools and solutions that can contribute to added value and profitability in the hydropower business whilst meeting requirements regarding availability, personnel safety and environment. It is a project objective to show how shutdown and pit stop maintenance methods can improve maintenance best practices in hydropower plants in the future.

5. Conclusions

Effective shutdown maintenance and pit stop maintenance in hydropower plants can reduce the maintenance outage time by reducing the time spent on each task, elimination of unnecessary activities, using module replacement and on-site manufacturing. It is important to make thorough preparations and plans before stopping the unit. Training and education are also essential success criteria. The experiences with shutdown maintenance in hydropower plants that are reported show how shutdown maintenance may form the basis for future pit stop maintenance in hydropower plants, and hence reducing both the loss of water, outage time and increase availability.

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