Modernisation of heat treatment equipment control systems

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Heat treatment equipment control systems need to be modernised at certain times for reasons that may be quite diverse, such as improving safety of operation, ensuring spare parts availability, improving functionality or improving energy efficiency. In contrast to new heat treatment equipment deliveries, modernisation projects include significant involvement of works on production equipment. Modernisation projects therefore require a specific approach with regard to planning, implementation and especially to risk reduction. This article aims to provide guidance for making the necessary considerations. Legal issues will be discussed as well as consideration of the optimal time for the modernisation in the furnace life cycle. Finally, some examples of typical modernisations will be presented.

Heat treatment equipment is an expensive investment which the user[1] wishes to utilise as long as it is economically sensible. This objective is achieved by replacing and repairing failed components, by inspecting and servicing the equipment, and sometimes also through preventive maintenance. At some stage, however, the point is reached where the user must take the decision either to extend use through modernisation, as illustrated in **Fig. 1**, or to dispose of the equipment.

Since heat treatment equipment is generally very robust and designed for a long lifetime, modernising the control system is frequently a sensible approach, and in most instances more cost-favourable than acquiring new equipment.

Definitions

- Spare parts service:

  Availability of replacement products to exchange defective or worn components.

- Repair:

  Reinstating the planned condition of equipment, as a rule in order to rectify wear-conditioned failures. Repair is generally carried out by replacing defective parts. Pursuant to DIN 31051, repair is a constituent part of maintenance [1].

- Inspection:

  Measures for identification and evaluation of the current condition, including identifying the necessary consequences for future use.

- Servicing and preventive maintenance:

  Measures to limit wear and to prevent damage, as a rule in order to maintain the planned condition of the equipment. Servicing and, if applicable, the preventive replacement of wearing parts occurs before a defect comes about [1]. Servicing and preventive maintenance are particularly important for heat treatment equipment because any technical systems failure is associated with significant hazards or losses.

- Modernisation (upgrading):

  Renewal and improvement of parts of the equipment, generally in order to extend and/or to improve the usability of the equipment

Problem with essential change

For a long time, modernisation was made more difficult through the prolonged debate about the interpretation of the EC's Machinery Directive[2]. Accordingly, used machinery having undergone an essential change needs to be upgraded to the safety level defined in the EC Machinery Directive and must be issued with a new EC declaration of conformity.

In accordance with the customary interpretation of the term "essential change" up until around 1999, in many instances the person making the change would have been compelled unnecessarily to adapt the whole machinery, and thus also componentry unaffected by

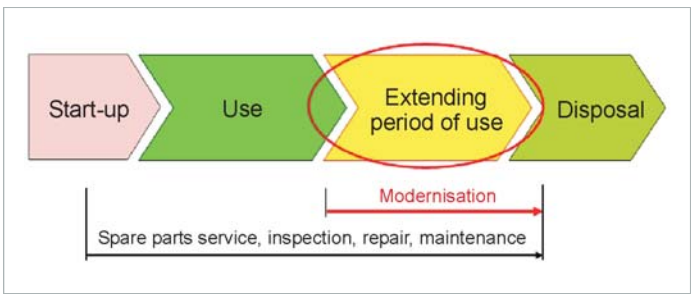

Fig. 1: Modernisation in the heat treatment plant life cycle

[1] The user is the utilizer of the heat treatment equipment. He is responsible for the safe condition of the heat treatment equipment.

[2] Directive 98/37/EC of the European Parliament and of the Council of 26 June 1998 on the approximation of the laws and administrative regulations of the Member States, which sets out a common safety level for prevention of accidents for machinery being placed on the market within the European Economic Area.

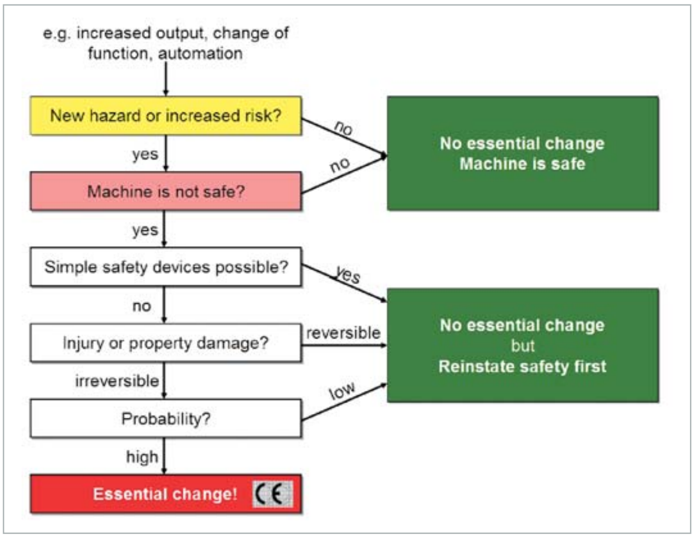

Fig. 2: Method to identify essential change [11]

The probability that a component will fail, changes over time, as shown in Figure 3. However, the failure probability is never zero. During the first period of being taken into service, there is a high probability of early failure on electronic components. These are generally covered by warranty.

During the period of use of the equipment, there are repeated occurrences of failures, also termed random failures. These failures cannot be predicted, and cannot be reproduced either. During this phase, the equipment is in a "stable" condition, which often lasts for ten years or longer. On complex and large-scale heat treatment equipment, the probability of random failures is increased solely through the number of components involved.

At the end of a component's lifetime, the failure probability increases markedly, particularly on components which are subject to wear. Therefore, the right time for preventive maintenance or modernisation is before the steep rise in failures due to wearing [6]. The failure rate takes the form of a bathtub, accordingly it is known as the bathtub curve[5].

An industrial furnace plant may have a lifetime of 30 years or more. However, this extremely long lifetime applies only for very few components. This means that over the lifetime of a heat treatment plant, some components need to be replaced several times.

In addition, two things should be borne in mind: the probable lifetime of a component to failure, and the period until the component is replaced by a successor model. A familiar example is the PC. Whilst a PC will run without problems for five years, a successor model is already on the market just after a few months. The shorter the successor model cycle, the more problematic the

the change, to the state-of-the-art. It is to be recalled that this machinery at its unchanged condition would have conformed to the regulations[3]. Undoubtedly this interpretation of the EC Machinery Directive did not reflect the intention of the legislators.

Since 1999, there has been an agreed interpretation which bases the interpretation of the term "essential change" on a risk analysis. The method is illustrated in **Fig. 2**.

Every change to used machinery, e.g. increasing output or changes in function, is firstly to be examined systematically according to DIN EN 292[4] or DIN EN 1050. The aim of the investigation is to determine whether new hazards have come about due to the change, or whether a risk already present has been increased. If the result shows that new or additional hazards are to be anticipated in significant scope, then there is an essential change [2, 3, 11] otherwise not.

After an essential change, heat treatment equipment is regarded as if it is being taken into service for the first time. This means that, as for new heat treatment equipment, the requirements pursuant to DIN EN 746 are to be respected.

If there are non-essential changes the existing equipment may be maintained. The legislature is thereby taking account of the economic interests of the users. Non-essential changes include also modernisation of control systems, if these do not give rise to any new hazards. All modernisations to increase safety are expressly desired.

Time to modernise a control system

The lifetime of electrical products is dependent on burden, product quality, period and frequency of use, as well as on ambient conditions or environmental influences. With electronic products, such as controllers or a PLC system, above all it is the period of use which determines the lifetime, as illustrated in **Fig. 3**.

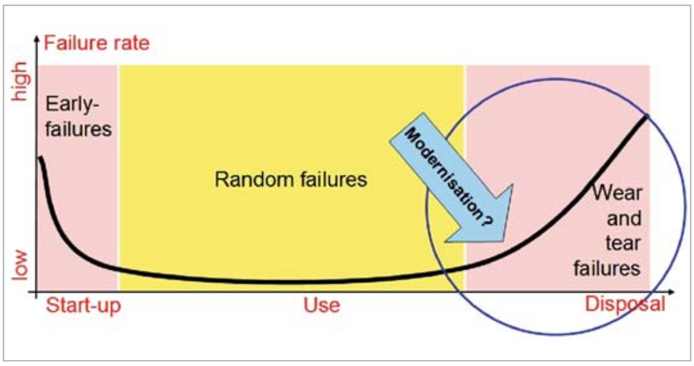

Fig. 3: Typical failure probability of electronic products

3 Used heat treatment equipment prior to validity of the EC Machinery Directive, or EN 746 must as a minimum conform to VDI 2046 "Sicherheitstechnische Richtlinien für den Betrieb von Industrieöfen mit Schutz- und Reaktionsgasen" ["Safety Engineering Guidelines for the Operation of Industrial Furnaces with Protective Furnace Gases and Reaction Gases"].

4 DIN EN 292 can be understood as an amplifying document of the EC Machinery Directive.

5 Strictly speaking, the bathtub curve (one synonym for which is the Weibull distribution for electronic product component failure) is only valid for a few components. The failure rate of the other electronic components then generally follows a similar pattern.

spare parts service, because of incompatibilities.

In case of modernising heat treatment equipment control systems, it is especially the typical period of use of the PLC which is interesting. This period is around 15 to 20 years. Taking the lifetime of the furnace as around 30 years, the optimum point in time for modernising the PLC is roughly at the midpoint.

Reasons for modernising the control system

Usually, one or even all of the following reasons are a trigger for modernisation:

1. Decreasing availability of spare parts, mostly associated with increasing spare part prices and decreasing possibilities for repair. Obtaining spare parts in near time is becoming ever more difficult. Often spare parts can only be obtained through exchange. This means that in the event of a fault, there can be very long and expensive downtimes.
2. Non-availability of experts, mostly associated with decreasing possibilities for servicing. Even a short time after notice of discontinuance of complex component has been given, the expert know-how starts to tail off.
3. Raising the safety level, to take account of the progressive state-of-the-art.
4. Expanding functionality, e.g. documentation requirements, heat treatment records, improved ease of operation, improved diagnostic possibilities or tele-service capability [10].
5. Improvements in flexibility and performance, e.g. through automatic recipe changes. Often, the performance range of old control systems is exhausted. For that reason, there are often no possibilities for expanding functions [9].
6. Energy-savings, e.g. through using frequency converters for circulating fans, pumps and ventilators [7].

Planning and implementing a modernisation project

There are some special conditions for modernisations which should be respected. In particular that downtimes during modernisation must be minimised, since the industrial furnace is only one part in a whole chain of capital- and cost-intensive production units.

Analysis and consultancy

The requirements of a system to be modernised are defined in a current status analysis. Often the investigated system is to be retained, but supplemented by new components. Various options for modernisation are worked out and budgeted.

The technical and organisational circumstances are investigated in detail. Interfaces are defined. A precise process scenario for modernisation measures is drawn up and the necessary expenditure determined.

Current inventory of the condition of the equipment

Fifteen years or longer after the initial start-up, it cannot be assumed that the documentation of any heat treatment equipment is up to date and that all changes have been documented. Unrecognised changes can result in reworking and cause irritable disruptions to the time schedule [8]. Therefore, competent and experienced modernisation partners can be recognised by the fact that they record and document the current situation in detail at the start of each project.

Planning and preparation

Planning and preparation call for a high degree of precision and experience. The replacement phase is prepared in the utmost detail. All replacement measures are planned down to the last screw. Replacement components are provided and pre-tested. Users are trained beforehand in using the new human machine interface and the new functions. In this way complex modernisations can be accomplished reliably with just a few days of lost production.

Realisation

In realising a modernisation project speed is just as important as the precision of the replacement measures. Even on comprehensive PLC migrations, the running test is started just after a few days. Sequences and process controls are optimised and the operating personnel are given training. Training can be limited to the scope of the modernisation itself, since the users are already very familiar with the equipment.

Risk reduction

For the user the risk of a modernisation is generally higher than that for new heat treatment equipment, because the existing heat treatment equipment already handles a part of the production capacity and the costs of lost production very rapidly outstrip the costs of modernisation. Minimising risk when modernising complex heat treatment equipment is therefore a critical success factor.

Even at the planning stage, measures must be taken to ensure that the installation is carried through in the shortest possible time and operations can be resumed again in good time. There is hardly any user who can risk long, cost-intensive downtimes. Inexperienced modernisation partners are therefore probably the biggest risk of all for users.

Further risks are a lack of documentation of the current condition, and poor support following a modernisation.

The risk can be reduced significantly if the moderniser can provide evidence of corresponding reference projects, has longstanding experience in the field of heat treatment equipment engineering and can demonstrate good service and maintenance support.

Examples of commonly-realised modernisation measures

Following are descriptions of a few examples of commonly-realised modernisation measures:

Example – PLC retrofitting

Around a decade ago, the Siemens PLC Simatic S5 series which up until then had dominated the market was replaced by a new PLC generation, the Simatic S7. This replacement goes hand in hand with increasing spare part prices and diminishing service and support options.

However, it is not entirely true that the shortage of original Siemens spare parts has led to higher prices, because a large number of other suppliers have specialised in supplying substitute spare parts. However, a genuinely large-scale problem is the lack of availability of Simatic S5 specialists, both at the supplier end and also on the user side.

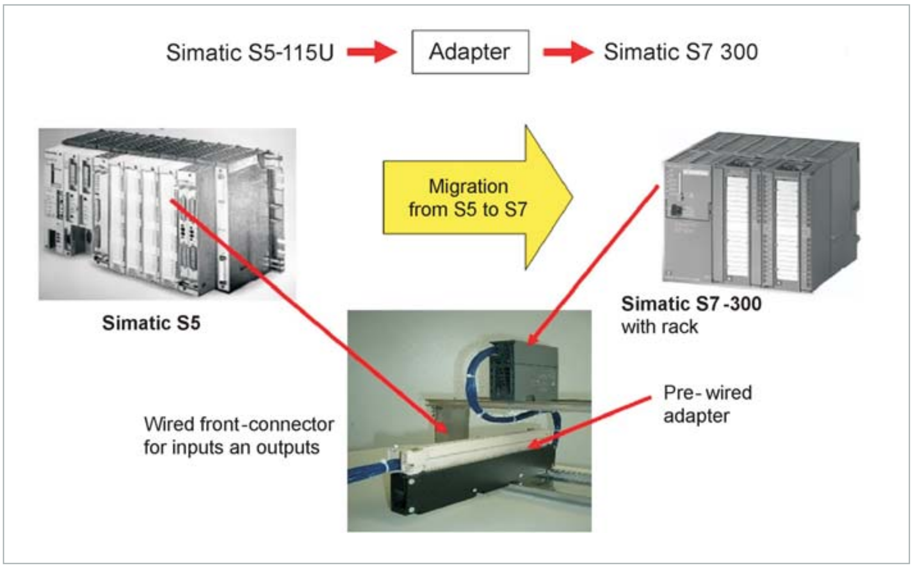

Fig. 4: Hardware replacement from S5 to S7 with adapters

Consequently, the benefits of migration from S5 to S7 are better availability of spare parts and support, improved diagnostic options, remote control capability, and a wide-range of options for expanding functionality. The disadvantages of migration are the relatively high costs of modernisation, especially for changing the human machine interface (HMI).

The challenge on a modernisation project lies, as previously mentioned, in achieving the shortest possible plant downtime for retrofitting. Hardware replacement is kept to a minimum by using adapters. This does not only save a lot of time, but also avoids wiring errors.

Retrofitting is carried out in three stages, as shown in **Fig. 4**. First, the old PLC is removed. However, the wires to the inputs and outputs remain connected to the existing electrical connectors. Secondly, pre-wired adapters are fitted in place of the old PLC units. The new Simatic S7-300, roughly half as tall and roughly the same width, sits on the new adapters. Third, the old connectors of the Simatic S5 are now plugged into the adapters. With this done, the major part of the hardware is already changed.

Unfortunately, changing the software is a far more complicated process. Software conversion can be automated to a limited extent only. In particular, changing the software for the HMI is done manually. Interfaces also need to be redesigned.

Once the hardware and software have been upgraded, the equipment must be taken into service again. The amount of work involved in this should not be underestimated, since every sensor, every valve and every motor must be checked for its interaction with the new PLC. Around ¾ of the modernisation costs are therefore taken up in wage costs.

Example – increasing the safety level

State-of-the-art is constantly evolving. Safety devices may have come to the end of their lifetime and become unreliable (**Fig. 5**).

Since the EC Machinery Directive expressly calls for modernisation of safety equipment, raising the safety level to the level of EN 746 is under discussion by practically every user. EN 746 [4] designates certain safety requirements as mandatory.

This includes: All systems influencing the safety of a heat treatment plant must be designed in such a way that a fail safe state is maintained at all times. Consequently, when a heat treatment plant is started up, a self checking of the control and safety equipment needs to be executed.

Heating must be persistently shut down in hazardous situations such as the temperature being exceeded, but also in the event of a lack of heating gas or air, or a failure of the exhaust fan.

Safe gasification of a heat treatment furnace is vital. Safety is guaranteed specifically through self ignition of the protection gas above its self-ignition temperature. Due to the high hazard potential redundant temperature controls are preventing the unintentional discharge of ignitable gases into the furnace and shut-down gasification in the event of faults. In redundant systems, more safety limiters are provided to perform the function than it is actually necessary. The presumption is that in the event of failure or the loss of one of these safety controllers, the other will take over the function in full. The principle applied here is to achieve the greatest possible reliability with as little redundancy as possible.

Prior to the ignition of the burners, the combustion chamber and the exhaust gas ducts must be purged. Purging ensures that the concentration of gas is well below the ignition limit. Purging time control is carried out as state-of-the-art, using fail-safe time relays which have been approved for the designated purpose.

Example – improving functionality

In principle, all old heat treatment plants can be upgraded to the level of a new plant. This is only a question of costs, and therefore of profitability [10].

Some examples of expanded and improved functionality are quality assurance measures such as heat treatment proof records, or increases in output by

Reliability and Safety

In day-to-day language reliability and safety are often used in the same breath. This is probably because they have some features in common: both relate to future events and have the character of probabilities.

If a component (or machinery or equipment) does not fulfil its intended function then it is **unreliable** [5].

Machinery or equipment is **unsafe** if a risk assessment indicates that safety measures are necessary in order to reduce the risk of damage.

Fig. 5: Reliability and Safety

automating prior manual processes [9]. A further often sought reason for modernisation is remote control capability to obtain expanded diagnostic options.

Example – improving energy efficiency

On electric motors, the proportion of energy costs within the total lifecycle costs is often over 90%. Pumps and fans are responsible for the major part of power consumption in a gas-fired heat treatment plant.

Using frequency converters to adapt the motor speed to the process needs opens up a significant potential for energy savings [12]. In addition, variable motor speeds can contribute to improved process management (e.g. for quenching), reduced wear on mechanical parts and reduced noise. Where there are variable process requirements, frequency converters can lower power consumption on previously permanently full-running equipment by 20 per cent to 50 per cent.

Speed regulation using frequency converters is highly energy efficient, since it means that the machine is only fed with the energy required for the process. The frequency converters also ensure energy-saving at start-up and power recuperation during braking.

Summary

Modernisation is not only a possibility to extend the furnace lifecycle but also a chance to increase availability, functionality and safety of heat treatment equipment. New user-friendly human machine interfaces make the equipment easier to operate and ensure the greatest possible process transparency. Higher automation and remote control services are further measures to increase productivity.

Compared to a new plant, a considerable advantage of modernisation is the lower training cost, since the operators are already familiar to the equipment and training can be limited to covering the parts being modernised.

Modernising also offers the possibility of improving energy efficiency especially for electric motors. The energy saving by using frequency converters can be as high as 30–50 per cent.

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