Reliability Precision Confidence Dynamics Power

Gas engines perform well in the start/stop environment created by the new power markets, but what are the safety implications of such operational patterns? Jan de Wit analyses the data on incidents for engines used in cogeneration applications in Denmark.

Safety matters

experience with the operation of gas engine CHP units

Some 800–900 gas engines are installed for cogeneration in Denmark, representing a total of some 950 MWe installed power capacity. In terms of numbers, pre-chamber engines account for some 25%, but represent some 60% of the installed capacity. Figure 1 shows the rated powers of natural gas-fired spark ignition (SI) engines in Denmark in 2006. In addition, there are some 150 small engines operating on sewage gas and some 65 engines operating on biogas, representing some 30 MWe installed power in total. Total operating time is estimated at 4 million hours per year.

Gas engines are able to perform short start-up or stop time with limited impact on engine service life

Most of the plants were installed between 1990 and 2000. New plants are still being built, but at lower annual number than in the mid-1990s. As an alternative to a major overhaul, a number of older engines are being replaced with more efficient versions or other models.

NEW POWER MARKETS

In the liberalized markets, electricity is often sold at 'pools'. At some pools, this means day-ahead bidding requests for each 24 hours of the next day (spot market). Bidding may take place with supplementary conditions so that, for example, at least three hours of continuous operation is achieved whenever the production unit bidding is accepted.

Bidding is based on a prediction of electricity consumption, likely production patterns for the next day and exact knowledge of own production costs. In countries with significant wind power installed, precise hourly wind predictions are a key factor.

The power transmission grid operators may also request bidding for other services in the deregulated markets. Such power grid services include:

- power balancing (i.e. uploading or downloading of production)
- back-up capacity (i.e. units for short remote or manual start, often to stop shortly afterwards)
- island operation services
- black-start services.

The first two services in this list are often well paid and typically require limited (if any) plant modifications. The technical demands for power production units in these markets will often be short response time and fast uploading or downloading.

Gas engine-based power/CHP units have excellent performance characteristics in this respect. When up and running, full-load operation is normally preferred to obtain best shaft efficiency but, during full load service, downloading can be offered for these hours. When the units are not running (due to low sales tariffs), uploading or back-up capacity can be offered. Gas engines are able to perform short start-up or stop time with

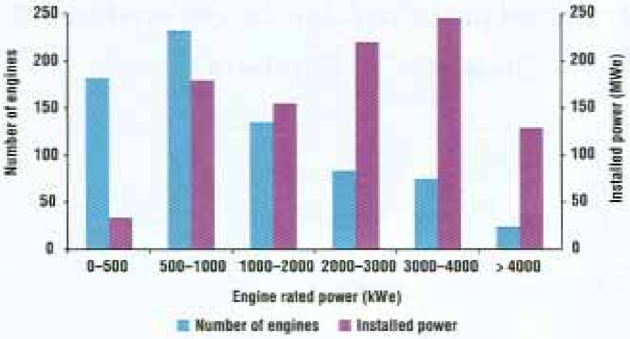


Figure 1. Numbers and nominal installed power of natural gas-fired spark-ignition engines in Denmark, 2006

limited impact on engine service life compared with other power or CHP prime mover technologies.

Heat-storage facilities enable a more flexible daily production, as heat can be stored if not needed in the hours when electricity is 'best priced'. A heat storage facility also makes it possible to operate the engines at their rated power in order to obtain maximum efficiency instead of part-load operation due to limited heat demand.

The back-up capacity market may also present a business opportunity for older reliable power production units. Instead of removing such units, they can be used to generate running income in such services. Special service and engine overhaul packages can be developed to ensure availability and short start-up time, instead of power efficiency optimization at continuous full load for such units.

Accidents at CHP plants using gas engines often occur during start sequences

Operation on the liberalized energy market generally leads to more start/stops for the units due to hourly fluctuation of prices/tariffs and possible power balancing needs. However, it is important to pay attention to safety aspects, particularly a possible build-up of unburnt hydrocarbons in the exhaust system (including manifold, ducting, silencer and heat recovery boiler).

ANALYSIS OF GAS ENGINE INCIDENTS

As for all other gas appliances, incidents with natural gas-fuelled engines and turbines are continuously registered and analysed in Denmark. Based on these reports, it can be concluded that many accidents at CHP plants using gas engines as prime movers often occur during start sequences. This is important for manufacturers, plant entrepreneurs, operations staff and owners, as the annual number of starts and stops is expected to rise as a consequence of the liberalized power market.

Figures 2 and 3 show statistics concerning incidents between 1996 and 2006 based on data from incidents known to the gas suppliers. Major mechanical breakdowns causing significant unplanned downtime are also represented (Figure 2a).

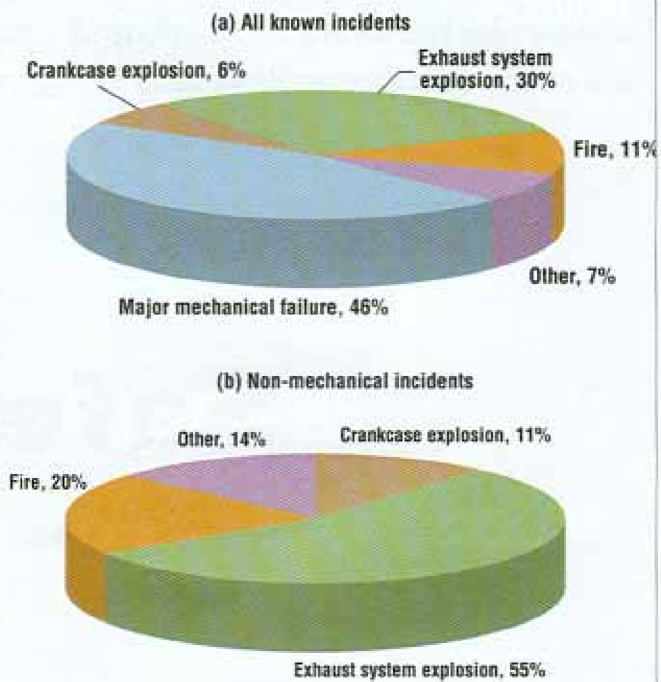


Figure 2. Type of incidents at gas engine CHP plants, 1996–2006

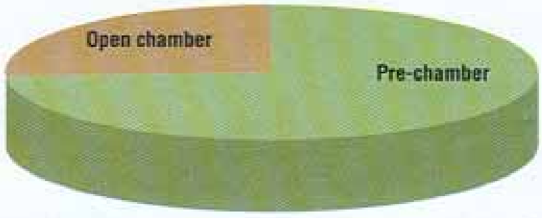


Figure 3. Distribution of incidents (on an operating time basis)

Mechanical breakdowns imposing no danger to surroundings are not considered accidents, but not all mechanical breakdowns are known or reported to the gas suppliers.

When mechanical incidents are excluded, explosions in the exhaust system are the most common type of incident (Figure 2b). The explosions often cause severe damage to the exhaust system and the buildings, leading to costly repairs and long down-time. They also pose a danger to operations staff.

Pre-chamber engines appear to be over-represented (Figure 3), possibly because of limited 'natural purging' during start-up due to a limited capacity of pressurized air for starting. Many of these units have relatively large exhaust system volume due to larger heat recovery boilers, multi-stage silencers and significant chimney tubing volumes.

SAFETY IMPROVEMENT PROGRAMME

The number of incidents during late-1990s led to the introduction of a safety improvement programme by the Danish safety authorities in 1998–2000. This programme included activities such as:

- discussion with suppliers about the redesign of sensors, control systems, auxiliary equipment, etc.
- revision and updating of national installation codes
- publication of good practice guides
- mandatory training for operations staff (particularly those responsible for taking action when alarms sound).

A newsletter focusing on safety has been posted to all natural gas-fuelled CHP plants since mid-2003. This newsletter is published some three times a year as a service by the gas grid distribution companies in Denmark. The aim is to keep safe operation at the forefront of the minds of plant owners and operations staff.


Pre-purge system for flushing the exhaust and dilute flue gases during start/stop sequence

TECHNICAL MEASURES TO IMPROVE SAFETY

A number of technical measures recommended by the Danish Gas Technology Centre (DGC) can be taken to improve the safe operation of gas engine CHP plants are outlined below.

- Forced purging (ventilation) of the complete exhaust system before starting or when stopping. This should be included in engine delivery/supply as a type-tested device. Alternatively, the control system should be prepared for this. To achieve optimum effect, it is recommend that forced purging continues at idling and part-load operation during start-up/shutdown as high concentrations of unburnt gas are often measured in the exhaust system.
- Limiting the number of start attempts (possibly making a distinction between cold/warm start). This should be integrated within the engine control system.
- Back-pressure electronic detection integrated within the engine surveillance system.
- Detection of misfiring, not just as a deviation from average cylinder temperature, but also based on an absolute temperature acceptance interval in each cylinder.
- Use of safety valves (spring-loaded and one-off) in the exhaust system and vacuum valves in the stack.

Spring type of explosion relief valve used in exhaust ducting

One-off type of explosion relief valve (must be replaced after use)

Forced purging will ensure that a new start after a possibly failed start attempt will be made with as little risk of combustible gases in the exhaust system as at the first start. Purging often becomes even more important for large pre-chamber gas engines, since purging by engine turning prior to start is usually reduced due to the limited compressed air reserves for starting. If hot items such as catalysts are present in the exhaust system at start, special care should be taken.

DGC has performed a number of measurements of emissions during start and stops at gas engine-based CHP plants with open-chamber engines and pre-chamber engines. The measurements have been made during normal start/stops and also included emergency stops.

Figure 4 shows an example of emissions during an ordinary start and stop. The emission sample point is downstream of the heat recovery boilers. The effect of forced purging before start on concentrations in the exhaust system of this gas engine-based CHP unit can be seen. The two-minute purging prior to opening

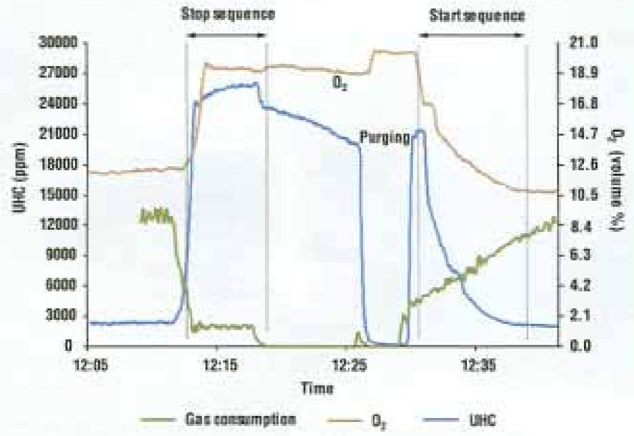


Figure 4. Concentrations of UHC and oxygen (O_2) in the exhaust system (parts per million) during stop and restart of a pre-chamber gas engine for cogeneration

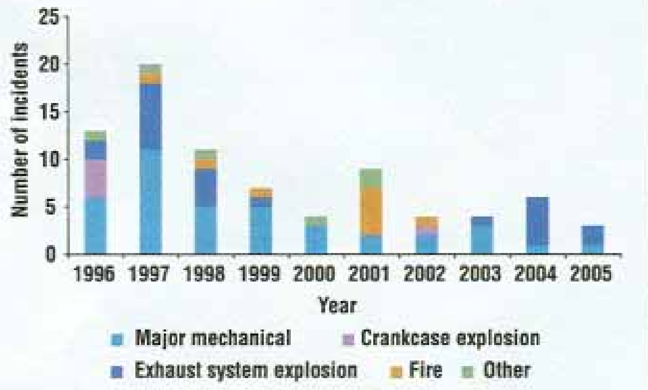
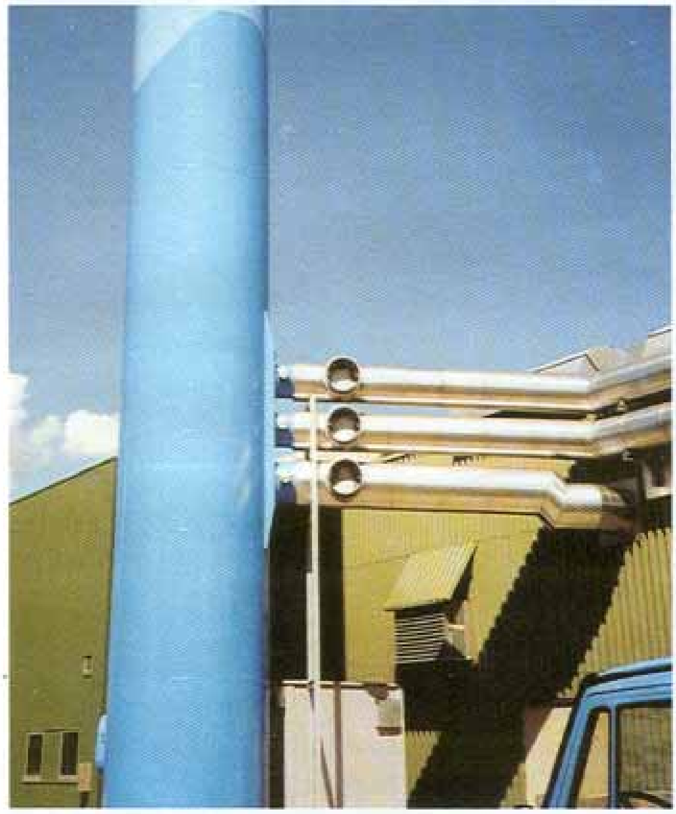


Figure 5. Number of incidents at gas engine CHP plants in Denmark, 1996–2006

of gas valve (gas release) at start almost completely eliminates the concentrations of unburnt hydrocarbons. Because purging is ended before gas is released, a peak of unburnt hydrocarbons can be found when gas is released. As stated above, DGC recommends purging is continued during idling and low-load operation.

A number of starts and stops (including emergency stops) were made at three different gas engine-based plants. The highest concentrations of unburnt hydrocarbons (UHC) were found during start at an open-chamber engine plant. More and similar measurements are now being made in connection with an ongoing project that aims to reduce the environmental impact of increased emissions during start and stops.



Vacuum valves at the chimney inlet to prevent collapse of the inner tubing during stoppage

CONCLUSIONS

A time series of incidents at the gas-fired cogeneration plants (Figure 5) suggests that the safety improvement programme/ initiatives launched in the late 1990s in Denmark has been effective. The number of incidents each year has fallen from some 15–20 to fewer than five. The target set by the Danish Safety Technology Authority is that the number of incidents should not increase from today's level.

The power sales structures and services required – and paid for – on the liberalized energy markets are advantageous for gas engine-based power/cogeneration plants. However, more starts in less time and more stops may be the result, making 'safe' start and stops even more important.

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