SAFETY ASPECTS OF CENTRIFUGES

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Aspects of the safety of centrifuges used in the process industries are discussed taking the widely used batch centrifuge as an example. Three aspects of safety are reviewed, firstly the recent BS standard and CE certification, secondly control systems and finally basket design and inspection. The purpose of the review is to illustrate both good practice and some common pit-falls rather than give a definitive overview. Whilst the discussion refers to batch centrifuges many of the comments applies to other centrifuge types.

INTRODUCTION

Centrifuges have the potential to be hazardous. This is a fundamental to their design. Similar comments apply to many items of equipment used in the process industry such as pressure vessels, dryers, pumps etc. For a typical 1.2 m (48") batch centrifuge basket spinning at 1200 rpm the stored energy within the basket is approximately 4 MJ and the peripheral speed of the basket is 168 mph (271 km/h). The energy stored in the rotating basket is equivalent to that of a Ford Mondeo travelling at 175 mph (280 km/h) or a 2.5 m^3 vessel pressurised with gas to 16 bar.

With speeds and energies such as these, perhaps together with a chemical hazard, there is a risk that a dangerous situation may develop. The safety of a centrifuge depends on the operation, controls, design and maintenance of the machine reducing this risk to an acceptable level.

Standards

The key standard for centrifuges is BS.EN12547:1999 'Centrifuges - Common safety requirements'. This standard, which covers industrial (excluding laboratory) centrifuges became active in July 1999 and supersedes BS767 upon which it is based. The 1999 standard is a type C standard, that is one that covers a specific type or group of machines. One important aspect of a C standard is that compliance ensures conformity with the Essential Health and Safety Requirements (EHSR) of the EC Directives. In the words of the standard itself (Annex ZA) 'Compliance with this standard provides one means of conforming with the specific essential requirements of the Directives concerned …' which are the Machinery Directive and Low voltage Directive. The C standard BS. EN12547 for centrifuges achieves this by referencing 30 other standards. These are listed in Table 1.

Whilst Table 1 may seem an exhaustive list there are certain hazards that the centrifuge standard does not cover. These are listed as:

- Thermal hazards
- Microbiological hazards
- Corrosive & erosive chemical hazards
- Flammable or explosive hazards
- Hazards caused by unsuitable hygiene involving food products
- ... plus other application specific hazards

SUBJECT	STANDARD
Actuators	prEN894-3
Danger zones for upper limbs	EN294
Design and specification	EN292-1 EN292-2
Electrical installation etc	EN60204-1, IEC60364
Electromagnetic compatibility	EN50081-2, EN50082-2
Emergency stop systems	EN418
Enclosures	EN61310-1
Guards	EN953
Indicating, marking and actuation	EN61310-1
Interlocking	EN1088
Lifting	ISO3266
Manual handling	prEN1005-2
Noise levels	ENISO3744, ENISO3746, ENISO4871, ENISO11203, ENISO11688, ISO9614-1, ISO9614-2, ISOTR11688-2
Operator displays	EN894-2
Packaging	ISO780
PLC control systems	EN954-1
Risk assessment	EN1050
Unexpected start-up	EN1037
Welding	EN729-2, EN729-3

Table 1: Standards referenced directly in BS.EN12547.

Clearly one or more of these may apply in many chemical applications.

From the perspective of a purchaser of centrifuges it is sufficient to specify that the equipment should conform to BS.EN12547 to ensure compliance with the various Directives and standards listed in Table 1.

CERTIFICATION

Certification in the form of declaration of conformity (CE mark) or certificate of incorporation is a necessary part of satisfying the various directives incorporated into BS.EN12547. It is an offence to supply equipment without the relevant certification and it is the responsibility of the manufacturer, importer or end supplier of the equipment to ensure that it has the necessary certification. These requirements apply to all new equipment, however they also apply to second-hand equipment and equipment that has been significantly overhauled or modified. This applies even if the modification or significant overhaul has been carried out by the current owner of the equipment for his own use. Inevitably these requirements are having a significant effect on the sale of second-hand equipment and refurbishment of older equipment.

If the equipment supplied cannot function independently and requires other items to form a complete machine (e.g. the addition of a drive, electrical control panel or control software) then a certificate of incorporation must be issued rather than a declaration of conformity (CE mark). The certificate of incorporation states that the equipment cannot be put into service until the complete machine has been issued with a CE certificate. For example, if a centrifuge without the control software is purchased from a centrifuge supplier then the purchaser will receive a certificate of incorporation from the centrifuge supplier. Prior to use the purchaser must take the necessary steps to CE mark the complete machine. On occasion this splitting of responsibility and differing perspective on the meaning of ‘function independently’ and ‘complete machine’ cause much discussion, some of it heated between purchasers and suppliers. Normally common sense prevails.

CONTROL SYSTEMS

Accurate measurement of basket speed is one of the most important safety signals for a modern batch centrifuge. A reliable speed measurement is necessary to ensure safety for many common events during centrifuge operation such as:

- Human access
- Operation of product discharge mechanisms
- Operation of feeding/washing system
- Basket integrity

Generally human access is only allowed at zero speed, whereas basket integrity requires that the maximum speed is controlled. However, feeding and/or ploughing often require an accurate speed measurement at an intermediate speed. To ensure safety at all times it is normally a requirement that the basket speed be measured continuously. The vast majority of batch centrifuges employ control systems that satisfy this requirement.

A second consideration is the effect on safety of a speed measurement system failure. BS.EN12547 requires that any speed measurement system is a category 2 control. This means that the measurement system is automatically checked at suitable intervals by the machine control system and that the checking interval is selected to ensure that a dangerous condition cannot be reached. For many centrifuges operating a repetitive cycle every 10 minutes or less with many actions per cycle it becomes necessary to continually check the speed measurement system.

Figure 1 shows a simple schematic of one approach. The PLC receives signals from two separate speed sensors and compares the signals to check that the speed measurement system is healthy. The scheme outlined in Figure 1 potentially has several defects. Firstly, the PLC is the main control element that ‘decides’ if a fault exists by comparing the two speed signals and takes the necessary remedial action as defined by its program. However, there is only a single PLC and no checks are made on the correct operation of this PLC, so any failure or program error within the PLC may compromise safety.

A second concern relates to the signal conditioners. There are two units (e.g. frequency to current converters) in Figure 1 that can be compared to one another by the PLC. However, in control schemes such as this it is not uncommon for the two signal conditions to be of the same type. This makes the system prone to what is known as common mode failure. Any problem in the design, installation or use of the signal conditioner which may cause it to fail, such as a susceptibility to electrical spikes or high ambient temperatures, are quite likely to cause both units to fail at the same time. The possibility of such a common mode failure lessens the benefit of having two systems checking one another.

Figure 2 shows a system that overcomes these concerns. It contains two signal conditioners of differing types (1 & 2) and two PLCs (1 & 2) again of a different type each containing a differing control

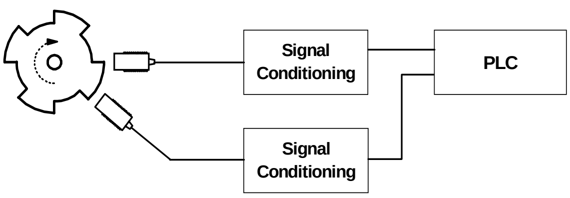

Figure 1: Simple speed measurement with checking.

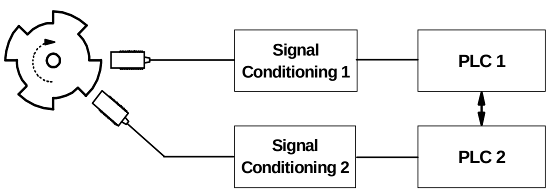

Figure 2: Modified speed measurement system with additional checking.

program. Checking takes place by communication between the two PLCs. A failure to agree on the speed, detected by either PLC, would cause the machine to take remedial action (e. g. shutdown).

The scheme in Figure 2 has high security and much greater immunity from the common mode failure. The costs of this approach need not be excessive. Typically PLC 1 is the main system control PLC and together with its power supply, racks and I/O cards may cost several thousand pounds. PLC 2 has a much more specific duty and can often be a small versatile brick type PLC costing perhaps 10% of the cost of the main control PLC. In addition, the additional PLC 2 can be used to check other safety critical signals, such as vibration, discharge mechanism movement etc., further reducing the cost impact whilst enhancing safety.

BASKET DESIGN

A large part of BS.EN12547 deals with the design and manufacture of the main rotating element in a centrifuge. For a batch centrifuge this is normally a perforated drum or basket which rotates at speeds of typically 1-2000 rpm. A major safety concern for any centrifuge is the long term integrity of the basket. Failure of the basket whilst rotating at high speed will destroy the centrifuge and possibly anything or anybody near it. Some users of large industrial centrifuges assume that the casing is designed to act as a containment device in the event of basket rupture. As indicated in the introduction, the energy stored in a centrifuge basket rotating at full speed is considerable and most casings will not contain a ruptured basket. For example a casing made of mild steel would need to be at least 50 mm thick to contain a rupture of a 1.2 m diameter basket rotating at 1200 rpm. Most centrifuge cases are typically 6-12 mm thick depending on the application.

Clearly the basket design must be such as to avoid rupture. BS.EN12547 considers two cases, steady loading and cyclic loading of the basket. The standard states that a centrifuge start/stop cycle shall be considered as cyclic loading and therefore it is clear that the majority of centrifuges and virtually all batch centrifuges must be designed for the cyclic case. The standard contains design guidelines for the static loading case, but no specific guidelines for the cyclic case.

The more start/stop cycles a centrifuge performs during its life the greater the significance of fatigue. Taking the example of batch centrifuge in the pharmaceutical industry, some machines operate with perhaps one cycle every two hours and ten cycles per week for perhaps a 15 year life of the centrifuge. This equates to 500 cycles per year and 7,500 cycles in total. Other industries, such as the sucrose industry, process at the rate of 20-25 cycles per hour for 23 hours per day and 300 days a year for 25 years. This equates to 155,000 per year and 3,875,000 over the life of the centrifuge. Most centrifuges operate with 5,000 to 50,000 cycles per year and fatigue is important.

The difference between the static and cyclic loading relates to the possibility of fatigue failure. Experience has shown that the design guidelines for the static case normally give an acceptable design for cyclic cases where the number of stress cycles is limited and the materials used have a good fatigue limit. The simple static design can therefore be used as a guide for the suitability of a basket subjected to cyclic loading but additional design calculations and/or material type testing may also be required. In some cases material testing can involve fatigue tests of fabricated components immersed in a sample of the corrosive slurry being processed by the centrifuge. Such testing is time consuming but provides the centrifuge manufacturer with invaluable data. Figure 3 shows a Broadbent test cell for performing such tests at elevated temperatures and pressures.

Unlike control systems there is no automatic method to check a centrifuge basket and any form of failure would be a major hazard. When designing the basket it is necessary to consider the expected intervals between inspection - typically a year. Whilst baskets are generally designed for an infinite or extremely long fatigue life the design should be such that if for any reason a fatigue crack becomes visible the day after an inspection it doesn't grow to a point where failure will occur before the next inspection. Fatigue crack growth is a complex phenomenon and for a component that will eventually fail by fatigue the majority of the life is taken up initiating the crack, and only a small proportion of the time (typically 10%) is needed to grow the crack from a point where it is visible to the point where the component fails. Figure 4 shows this effect graphically for a basket with a small pre-existing defect (e.g. casting porosity or a sub standard repair).

BASKET INSPECTION AND MAINTENANCE

Inspection and maintenance play a major role in the life and safety of a

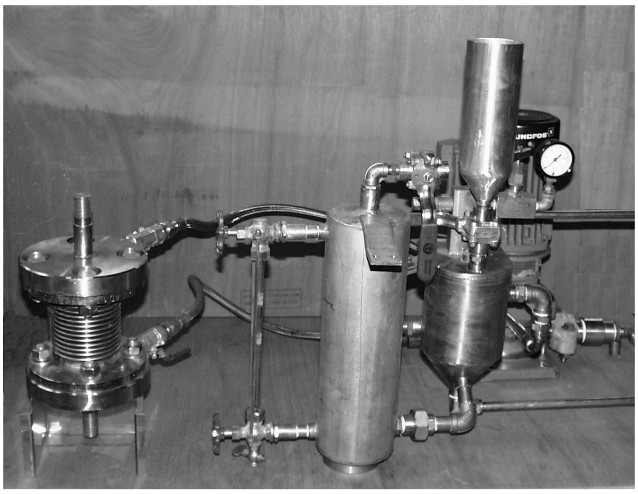

Figure 3: Fatigue test cell.

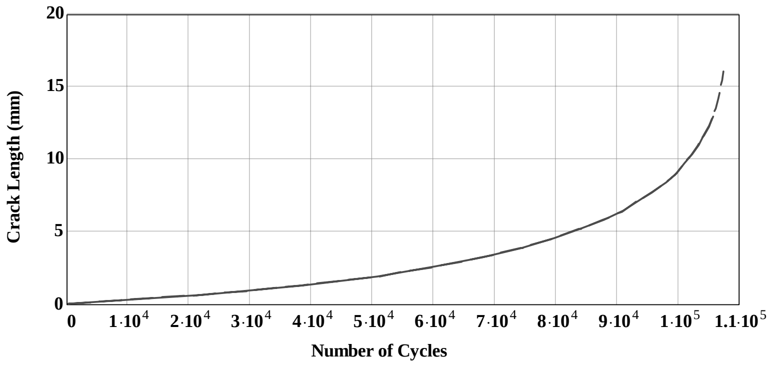

Figure 4: Crack growth rate against stress cycles.
(Carbon Steel (Grade 50/EN10025 S355) Shell, 150 MPa nominal hoop stress, 5 mm perfs.)

centrifuge basket. Repairs to the basket may be necessary during the 15-25 year life of the centrifuge due to erosion, corrosion or mechanical handling damage to inert coatings. Correct repair procedures are vital to ensure that no crack is introduced by an unsuitable repair procedure and that the original design calculations and assumptions are not invalidated by the use of unsuitable repair materials.

Inspection should always be in accordance with the original equipment manufactures latest procedures, which for an old centrifuge may be different from those included with the original manual. Basket inspection procedures are specific to individual centrifuge types and manufacturing methods. However procedures generally focus on:

- The general loss of material from the basket (e.g. by erosion or corrosion).
- The presence of cracks. Any basket found to contain a crack in the basket shell should be taken out of service.
- Damage to any inert coatings.

Basket inspections should be carried out regularly at the specified intervals by qualified and experienced personnel.

SUMMARY

This paper discusses some aspects of centrifuge safety which may be of assistance to users and prospective purchasers of centrifuges. The key points are:

- The C standard BS.EN12547:1999 incorporates all the essential health and safety requirements. Special site requirements, use in a hazardous area, etc. require adherence to additional standards.
- CE certification is required for second hand, significantly overhauled or modified equipment. Only complete machines can carry the CE mark. Incomplete machines (e.g. no controls) carry a certificate of incorporation.
- A good understanding of centrifuge operation and the designs of centrifuge controls are necessary for safe operation.
- Basket design is a complex issue and BS.EN12547 gives only limited guidance on design for cyclic duties.
- Quality maintenance and inspection of any centrifuge is necessary for the long term reliability and safety. An understanding of general centrifuge design requirements and limits is important when repairing key items such as the basket.

Centrifuges are versatile items of process equipment and with care in the design, maintenance and inspection they will give many years of safe and reliable operation.