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PREVENTION

OF

EXPLOSIONS IN FANS

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FOREWORD

Protection against explosion in fans is a very important issue for fan manufacturers.

The present document, giving an exhaustive analysis of this question has been prepared by Prof. Dr. Hans WITT. The EUROVENT WG 1 « Fans » considered that it contains extremely useful information and it was proposed to publish it as a EUROVENT Document.

The English translation was assured by W.T.W. CORY.

Introduction

The European Commission in Brussels has been working very hard at getting to grips with issues of safety in association with the operation of machinery. One concrete result of this effort has been the emergence of DIN EN 292, Parts 1 and 2, " Sicherheit von Maschinen " [Safety of Machinery] [1].

This Standard lays a heavy burden of responsibility on the manufacturer, who is required to carry out an evaluation of risks and to endeavour "...to predict all situations which could lead to injuries or which could be prejudicial to health as a result of the hazards which they pose." This includes the requirement to build the possibility of misuse into his calculations.

The draft version of DIN EN Standard 1127, Part 1, which has just been published [21], is the first to lay down regulations showing what action is to be taken to prevent fires and/or explosions from breaking out or occurring in machinery. There are also other Standards in the pipeline. It is required that an assessment be made of the effect of an explosion in terms of potential personal injuries and property damage, also of the size of the area likely to be affected.

The European Council has expressed the wish that work on Standards should incorporate equipment and protective devices for use above and below ground in a single guideline [2], since "...the types of hazard, protective action and testing procedures are very similar or even identical."

In the case of fans which are used to propel explosive gases or dusts, it is of paramount importance that they do not create any ignition sources, such as through contact between rotating and fixed components. It is a well-known fact that the mining industry allows only two combinations of materials [3,10] - silumin impellers with a protective aluminium lining or stainless steel impellers with a protective lining made from a brass alloy. There are also other international and German Standards and guidelines, such as VDMA 24 179 [20] which impose similar restrictions.

There would appear to be an undeniable case for a major alteration to VDMA 24 169 [19] which also allows other combinations of materials to be used. In this paper, we shall be investigating the experimental bases used in appraisal of the ignition risk associated with various pairs of materials and we shall be making certain recommendations based upon our current state of knowledge. The regulations will definitely be tightened up in the future and this is a result of the requirement laid down in Chapter 2 in [2] which states, *inter alia*, that there must be no effective ignition sources, even where two rare faults occur simultaneously.

Fan manufacturers and plant designers - and users - would be well advised to fall into line with the new regulations now and to revise their designs. DIN EN 292 has created a new scenario. In the event of an accident caused by a fan, it will be no defence to refer to an earlier Standard since it is the responsibility of the manufacturer, the plant designer and the plant user to see to it themselves that the independent risk assessment which could have prevented the accident is carried out.

1. A REVIEW OF THE LITERATURE

The Literature features a number of reports on investigations which deal with the ignition risk which occurs where two materials come into contact with one another in the presence of an explosive gas-and-air or dust-and-air mixture. This can happen in a fan if the rotor strikes or rubs against the casing.

Abstracts from some of these reports are set out herein below and compared with one another, with comments upon them. This comparison was fraught with serious difficulties in view of the fact that the test conditions were not always reproduced with a sufficient degree of accuracy. Careful editing was needed in order to be able to compare the results to the greatest possible extent and to represent them in the same diagram without falsifying their meaning.

The majority of the reported investigations into the explosion risk which occurs where two materials come into contact with one another were carried out by mining institutes, which obviously focused their attention on methane. Tests with propane and ethylene were only carried out for the purpose of comparison, in order to achieve a greater degree of safety in terms of methane explosions, since these gases have lower ignition energy levels than methane.

Work with industrial fans needs to cater for other gases which can have lower ignition energy levels (Table 1) and which, as a result, pose a far greater risk of explosion than methane or ethylene. For instance, the ignition energy of acetylene is only 7% of that of methane; acetylene is a substance which can be used in the chemical industry, for instance, as the basic material for use in synthesis. Acetylene can also circulate freely wherever it is used for welding or burning. Hydrogen, for example, can occur where there are accumulators or through unintentional reactions between acids and metals.

A review of the results from the sources considered here is shown in chapter 9 " Trial results "[1] after we have dealt with test installations, ignition processes and ignition parameters. The risk arising in connection with electric motors will not be covered in this paper, since it forms part of another group of Standards.

[1] The context suggests that the punctuation in the German text has been misprinted.

2. THE PHYSICS OF THE IGNITION PROCESS IN FRICTION AND IMPACT SPARK GENERATION

A distinction needs to be made between the different forms in which the two materials can come into contact with one another : impact and friction (defined as contact between rotating and fixed components), friction combined with impact and grinding (defined as back and forth movement of one material on another). The latter has no real place where fans are being considered.

BARTKNECHT [4] compared the potential for ignition between friction sparks and friction-impact sparks. The arrangement used in the trial to generate friction sparks is shown in Fig. 1 and that used for friction-impact sparks is shown in Fig. 2. The disks which were used were 10mm thick and had a diameter of 150mm.

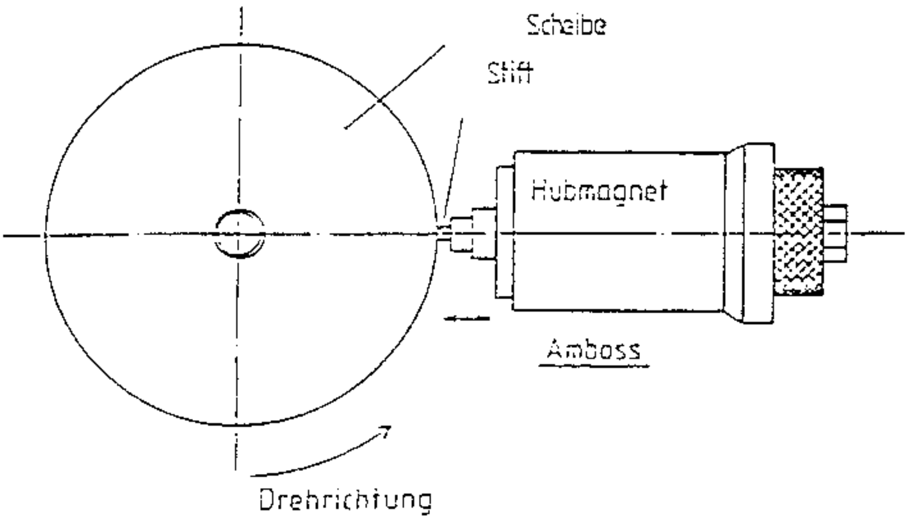

Fig. 1 Device for generating friction sparks[4]

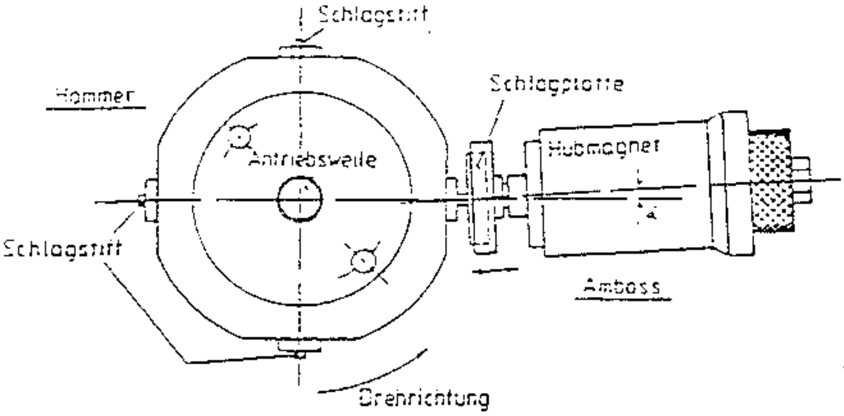

Fig. 2 Device for generating friction-impact sparks[4]

Amboss	fixed component	Scheibe	disk
Antriebswelle	drive shaft	Schlagplatte	striker plate
Drehrichtung	direction of rotation	Schlagstift	striker pin
Hammer	hammer	Stift	pin
Hubmagnet	lifting magnet		

Other authors used similar arrangements, but most of them used disks with greater diameters. For example, POLLAK and MOHR [10] used 0.9m disks, POWELL [9] 0.6m. All the tests produced similar results in that they showed that impact sparks were appreciably less likely to cause ignition than were friction sparks.
This being the case, we shall confine our thoughts to tests with friction sparks. Here, we need to consider not only ignition due to sparks, but also a second ignition mechanism based upon hot spots generated by friction.

In June 1987, BARTKNECHT carried out very comprehensive tests for CIBA-GEIGY; these tests throw some light upon the physical factors which affect the occurrence of ignition due to friction sparks or hot spots. His objective is actually to avoid dust explosions in mills, but the scope of this work and the careful documentation allow major conclusions to be drawn in terms of the design of explosion-proof fans.

Not unexpectedly, BARTKNECHT found that there is a whole host of parameters which play a decisive role in determining whether or not ignition will take place. They include, in particular :

a) the nature of the gas or dust which burns during the ignition process;
b) the concentration of the gas or dust;
c) the material used to make the rotating disk; in the test arrangement, this was investigated in conjunction with a pin which was pressed onto it in the ignition test;
d) the material from which the pin is made;
e) thermal conduction in the pin and in the disk;
f) the diameter of the pin which is being pressed onto the disk;
g) the pressure at which the pin is pressed onto the disk;
h) the speed at which the disk is rotating, also the disk diameter;
i) the length of the test
j) hardness of the disk and the pin;
k) areas of turbulence in the test medium;
l) ambient temperature;
m) humidity;
n) the oxygen content in the air;
o) the presence of contaminants;
p) disk roughness.

Given the number of parameters at work, it is hardly surprising that different workers can arrive at different results and it is quite conceivable that a combination of materials which is quite capable of igniting could generate no ignition whatsoever in some tests if, for instance, the contact pressure is too low or if turbulence is excessive.

It is virtually impossible for a manufacturer to predict what conditions, in other words, what combination of the various factors a) to p), will actually be present in practice in a fan at the moment when a hazard develops. This applies particularly to off-the-shelf fans. The fact that a single experimental worker has identified ignition means that the combination of materials used needs to be classified as hazardous, but the absence of ignition under special test conditions does not mean that the combination of materials which was used can be classified generally as "safe".

3. THE IGNITION PROCESS

Ignition as a result of the formation of sparks or of the appearance of hot surfaces as a result of friction is not an instantaneous event.

In ignition tests involving friction sparks, one factor which can play a part is a phenomenon in which particles of one of the materials are torn away from their molecular framework and these then become embedded in the other material. In the case of steel and brass, for example, steel particles can become embedded in the brass, with the result that, after a while, compact steel is rubbing against embedded steel particles, a process which can lead to unexpected late ignition, after say 10 or 20 minutes, such as would never happen with the materials in their initial condition.

It can also take some time for the temperature to peak in the case of ignition due to hot surfaces and this is not due solely to the normal heating/time curve. Where the test lasts for a fairly lengthy period, this can cause increased roughness, with an attendant rise in the coefficient of friction and a correspondingly higher degree of heating. Cold processing during the friction process can also lead to a rise in the coefficient of friction.

In many plants, one must allow for the fact that fans can be damaged and start grinding, but that this can go undiscovered for long periods. Fans are often installed in separate areas where they escape constant supervision.

Unfortunately, test reports lack not only accurate details of the other test parameters a) to p), but also, on many occasions, details of times and this restricts the extent to which tests can be compared. In several cases, there are grounds for suspecting that ignition would have taken place had the tests not been terminated before this could happen.

4. IGNITION ENERGY

Ignition energy is defined as the smallest amount of electrical energy in a condenser which is needed when discharging across a spark gap to ignite an explosive mixture of a gas or dust and atmospheric air.

Table 1, shown below, gives the lowest levels of ignition energy for a few common gases in the air mixtures which create the best possible conditions for ignition [5].

Substance	Minimum ignition energy (at the mixture which best promotes ignition) mJ	Ratio of concentrations of the mixture which best promotes ignition to stoichiometric mixture	Mixture which best promotes ignition % (volume)
Acetylene	0.019	1.1	7.7
Acrylonitrile	0.16	1.7	9.0
Ammonia gas	680.00		
Benzene	0.20	1.75	4.7
Butadiene-1,3	0.13	1.4	5.2
Butane	0.25	1.47	4.7
Cyclohexane	0.22	1.75	3.8
Cyclopropane	0.17	1.45	6.3
Diethyl ether	0.19	1.53	5.1
Dimethyl butane-2,2	0.25	1.55	3.4
Ethane	0.25	1.17	6.5
Ethyl acetate	0.46	1.3	5.2
Ethylene	0.07		
Ethylene oxide	0.065	1.3	10.8
Heptane	0.24	1.82	3.4
Hexane	0.24	1.71	3.8
Methane	0.28	0.88	8.5
Methanol	0.14	1.2	14.7
Methyl acetylene	0.11	1.3	6.5
Methylethyl ketone	0.27	1.4	5.3
Methyl cyclohexane	0.27	1.8	3.5
i-Pentane	0.21	1.5	3.8
n-Pentane	0.28	1.34	3.3
Pentene-2	0.18	1.6	4.4
Propane	0.25	1.24	5.2
Propylene oxide	0.13	1.4	7.5
Carbon bisulphide	0.009	1.2	7.8
Tetrahydropyrane	0.22	1.6	4.7
Hydrogen	0.019	0.8	28

Table 1 : Minimum ignition energy for common gases mixed with air[5]

Table 2 [2] which follows shows approximate ignition energy figures in dust explosions. Accuracy leaves something to be desired, since the Literature contains data with deviations of one power of ten. One of the reasons for this is probably the effect of particle size, dust concentration and turbulence. In the case of dust deposits, far lower minimum ignition energy figures were measured in some instances than was the case where the dust was floating.

Literature	Dust	Minimum ignition energy in mJ	
		Dust-air mixture	Dust deposit
Rep. Inv. 5753	Cereal dust	30	—
	potato starch	25	
	maize starch	30	
	sugar powder	30	
	wheat starch	20	
Rep. Inv. 5971	rubber	10	—
	phenol formaldehyde	10	
	polyethylene	10	
	polystyrene	15	
	shellac	10	
Rep. Inv. 6516	Aluminium	20	2
	Magnesium	20	0.24
	Zircon	5	0.001
Rep. Inv. 6597	Lignite	30	—
	Charcoal (hard wood)	20	
	Coal	30	
Rep. Inv. 7132	Phthalic acid anhydride	15	
	Sulphur	15	—
BAM measurement [2]	Red phosphorus	—	0.2
Eckhoff Comb. Flame 24	Aluminium	8	—
	Sulphur	1.5	

Table 2 : Ignition energy of dust-air mixtures [5]

BARTKNECHT [4] found some figures in his own measurements - Table 3 - which differ markedly from those shown in Table 2. Whilst floating dusts tend, in general, to show higher ignition energy figures than gases, ignition temperatures are markedly lower than, for instance, those which apply to hydrogen and methane. This is a point which merits particular attention and is one with which we shall be dealing in greater detail below.

[2] It is not known what is meant by " Rep. Inv." or "BAM" in this context.

Type of fuel	E_M (mJ)	T_Z (°C)
Wettable sulphur	< 1	270
" Irgawax " [3]	1	330
Cellulose	10	350
Lycopodium	2	370
Soya meal	50	380
Maize starch	10	400
Lactose	50	400
PE dust	1	420
" Lignocel " [3]	10	420
Pea meal	100	430
Slurry	5000	430
Wheat dust	50	450
" Epoxi " [3]	2	460
Theophylline	< 10	470
" Orasol red " [3]	1	500
Saar coal	10	550
Butane	0.27	365
Propylene	0.27	455
Propane	0.27	470
Hydrogen	0.012	560
Methane	0.31	595

Table 3 : Minimum ignition energy E_M and ignition temperature T_Z for the fuels used for investigations into the ignition efficiency of mechanical sparks[4]

[3] It is assumed that this is a proprietary name

5. IGNITION SPARKS

DITTMER[18] dealt with the ignition properties of friction and impact sparks. He describes how friction and impact sparks form when small particles are torn away from a part which is being subjected to mechanical stress and are then heated to such a high temperature by deformation energy that they radiate light. One factor which determines deformation work and, hence, the temperature of the sparks, is the strength of the material concerned. For instance, when steel is being turned, with approximately 90% of the deformation energy which is expended going into the chip, the temperature at the surface of the chip is in the region of 896°C where steel with a strength of 400N/mm is being used and in the region of 1089°C where the strength is 800N/mm.

Ignition does not occur in most cases until a secondary reaction takes place with oxygen in the air. Small particles of steel which have been rubbed off are often in sizes of between 0.1 and 0.01mm, which corresponds with an ignition temperature of 500 to 800°C in steel. Combustion of the steel particles raises their temperature to between 1700 and 2300°C, depending upon the size of the particles, alloy components and other factors. Such sparks ignite very easily. It is impossible to define a set ignition temperature for gas/air mixtures where ignition takes place due to fixed or fluid sparks. The smaller the spark, the higher the temperature needs to be in order to cause ignition. For its part, the size of the particles depends upon the materials involved as well as upon the separation mechanism (impact, friction, grinding, cutting).

In theory, friction sparks can cause several material combinations to ignite. There is a particularly high risk associated with friction sparks generated between metals and rocks such as flint or quartz, where it appears to matter little what metal is used, provided that it is sufficiently hard. In tests with picks used in the mining industry and gravel or pyrite layers in methane/air mixtures, ignition occurred with tips made from engineering steel, tungsten steel, chrome-nickel steel, tungsten carbide and bronze. This was explained by the high degree of hardness and the poor conductivity of the rocks.

6. READINESS OF GASES AND DUSTS TO IGNITE

In friction spark tests with gases and dusts, the readiness of the mixture to ignite depends upon the ignition temperature and the minimum ignition energy. Since the minimum ignition energy of dusts is relatively high (see Tables 2 + 3), it is difficult, if not impossible, to ignite dusts with sparks. Despite the fact that wettable sulphur ignites at a low temperature in the region of only 270°C, a sulphur dust-air mixture is extremely difficult to ignite with sparks, in contrast with hydrogen, with an ignition temperature of 560°C. The reason for this is that the ignition energy for the sulphur/air mixture is around 1mJ, whereas the corresponding figure for a hydrogen/air mixture is virtually 10^{-2} lower.

If hot areas are created during the friction process, the relationship is reversed, as BARTKNECHT[4] has shown. In view of their sizeable mass when compared with friction sparks, hot areas have a relatively high energy level, with the result that sulphur dusts and other dusts with their low ignition temperatures at hot spots are very much easier to ignite than hydrogen/air mixtures.

It may, therefore, be assumed that whilst the combination of materials represented by the wheel of the fan and the fixed components may be spark-proof, there is still a risk of gas explosions due to the initial ignition of dust by hot friction points if combustible dusts are allowed to make the fan dirty.

This shows how important it is that materials should have good thermal conductivity. At least one of the components should be soft so that it can be pushed out of the way and thereby stop the friction process or, at the very least, cause a substantial drop in contact pressure. Materials with low melting points are of particular interest since these can reduce contact pressure by melting before the temperature at the surface can become dangerously high.

In situations where there is a heavy build-up of dust, there may be a need to install a filter upstream from the fan. Where this is the case, periodic inspection and cleaning will always be needed where the risk of occasional dust accumulations cannot be ruled out.

7. THE EFFECTS OF TEMPERATURE

With the help of special heating facilities, BARTKNECHT was able to raise the temperature to 100°C in the arrangement which he used for his tests. The grinding disk was made from St37 steel. The tests are reproduced in the table below. In the tests, the disk was rotating at 4000min^{-1}, which is equivalent to a peripheral speed of 31.4m/s; the contact pressure was 6kp ≅ 60N.
The results are reproduced in Table 4.
Here, "O" indicates that ignition was attributed to the hot surface of the pin, whilst "F" indicates that ignition was attributed to sparks.
Even at a slightly raised temperature, there is a markedly increased tendency to ignite in evidence in comparison with 20°C. Pairs of materials which cause no ignition under the selected test conditions (low peripheral speed and contact pressure) always ignite at raised temperatures.

The greater readiness to ignite at raised temperatures is also shown by the fact that gas mixtures with a low combustible gas content become capable of ignition. This is very pronounced, particularly in the case of methane in contrast with butane, where the methane concentration for the lower ignition threshold falls by 46% at 100°C. This test was carried out with grinding disks made from St37 steel (Fig. 3).

Pin material		St 1.1740	St 37	St 1.2842	V2A
Combustion gas	T (°C)	Type of ignition :			
Methane	20	no ignition			
	40	F / O	no ignition		
	60	F / O	F / O	no ignition	
	100	F	F	F	F / O
Butane	20	F	no ignition	F / O	no ignition
	40	F	F / O	F / O	F / O
	60	F	F / O	F / O	F / O
	100	F	F	F	F / O

Table 4 : Types of ignition with grinding sparks generated by steel in combustible gas / air mixtures at various temperatures T - 6mm pins -

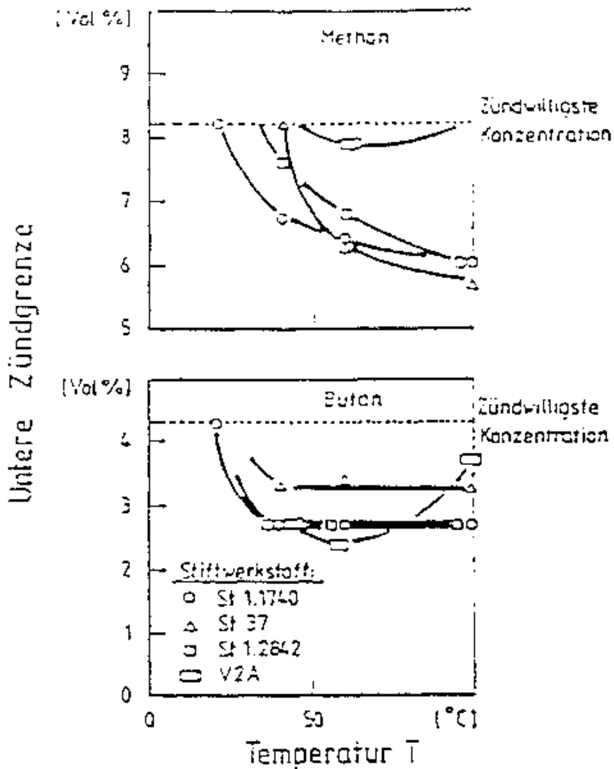

Fig. 3 : Steel friction sparks : the effect of temperature on the lower ignition threshold in combustion gas air mixtures[4]

KEY

Butan	butane	Temperatur	temperature
Methan	methane	Untere Zündgrenze	lower ignition threshold
Stiftswerkstoff	pin material	Zündwilligste Konzentration	concentration most ready to ignite

Unfortunately, there are no corresponding investigations into the effect of temperature for the combined use of silumin and rolled aluminium, also of steel and brass alloys, which are amongst those used in the mining industry and which are considered to be relatively safe. There is every reason to fear, however, that, where gas temperatures are raised, even these pairs of materials, which are otherwise regarded as being "safe", can generate friction sparks or hot spots which can cause ignition. This is of great practical significance. The temperature in many mines is considerably higher than 20°C. Temperatures can also be raised in process technology and in paintshops (stove enamelling) etc.

8. EXPLOSION CATEGORIES USED TO DATE

If an appraisal is to be made of the suitability of combinations of materials in fans, it is important to note the special conditions which obtain in the specific areas in which the fans are designed to work where there is a risk of explosions.
Areas in which there is a risk of explosions are those in which combustible gases, vapours, mist or dusts can occur at concentrations which can ignite when mixed with air and in which combustion will spread automatically once ignition has taken place. Where there is some doubt as to whether or not there is an explosion risk, the final decision will rest with the competent supervisory authority.

In the past, VDE 0165/9.83 distinguished between 5 danger areas for electrical components. The same classification was used in the case of fans. The new Standard - DIN EN 1127 (Draft) has 6 areas.
According to DIN EN 1127 (Draft), " Planning, construction, testing and certification requirements in respect of machinery and operating facilities...... are laid down individually in B and C Standards." Here, the draft Standard calls for consideration to be given to the various properties of the combustible substances. There is going to be a difficult and, possibly, protracted transition period. Here, we shall provide an initial outline of the regulations as they have stood to date. In a later chapter, we shall be reporting on the new area breakdown and we shall be suggesting how the new requirements will probably have to be met - on the basis of our present knowledge.

Area 0 : Areas in which gases, vapours or mists are present, either permanently or over long periods, in concentrations which could explode.
In this area, no explosion-proof electric motors may be used, regardless of the type of protection used. Fans may only be used in this area if they have been accepted specially by the PTB (Federal Physics & Engineering Establishment).
Figs. 4 and 5 show axial fans for use in area 0, these being operated by pressurised water or compressed air turbines. These fans are designed for use on marine vessels. Fig. 6 shows a radial fan in which the water-powered Francis motor is situated outside the air current.

Area 1 : Areas in which gases, vapours or mists occur occasionally in concentrations which can cause an explosion.
Electric motors may be used in this area if they fall into the explosion protection category "Pressure-proof casing" or "Increased safety".
It is the type of gas, vapour or mist which determines which group and temperature category needs to be selected, Table 14.

Fans may be used in this area. Hitherto, it was generally enough for them to satisfy the regulations laid down in VDMA 24 169 Part 1. This regulation will not be sufficient in future, following the introduction of tighter safety requirements in [1]. The mining industry already operates to stricter regulations which exclude, in particular, the use of steel impellers in conjunction with steel casings. VDMA Standard leaflet 24 179, which deals with extractor fans for wood dust and chips, also rules out the use of steel with steel. International safety regulations also mean that this combination may not be used on ships either[6].

Area 2 : Areas in which gases, vapours or mists are only rarely present in concentrations capable of causing an explosion and even then only for short periods.
Electric motors in the explosion protection category "Pressure-proof casing" or "Increased safety" may be used in this area. Motors which have not been type tested, but which satisfy VDE 0165/9.83 in relation to the maximum surface temperature and EN 50 014 in respect of blowers and blower hoods, may also be used.

For fans, it is the regulations in VDMA 42 169 which have applied hitherto in Germany. According to DIN EN 292, risk assessment for machinery should include consideration not only of the probability of a fault, but also of the extent of the damage arising as a result of any fault. This has, for instance, long been normal practice in the nuclear power industry.

So far as the fan manufacturer is concerned, only under exceptional circumstances will he be able to make such an assessment of the consequences of an accident, since he does not have adequate knowledge of the conditions under which the fan is to be used. The best course of action is, therefore, to continue to follow the line of least resistance and to take the same safety precautions as those which apply in area 1.

Area 10 : Areas in which dusts can cause a dangerous atmosphere in which explosions can occur and this either over a long period or frequently.
The rules which apply to electric motors and fans are the same as those which apply to area 0.

Area 11 : Areas in which allowance needs to be made for the fact that dust deposits can occasionally be blown into the air for short periods by eddying currents, thereby creating a dangerous atmosphere with the risk of an explosion. Here, the rules which apply to electric motors are the same as those which apply to area 1, with the added proviso that the rating plates for motors which have not been type tested must be marked specially. In the case of fans, it is the rules in VDMA 24 169, Part 2, which apply.

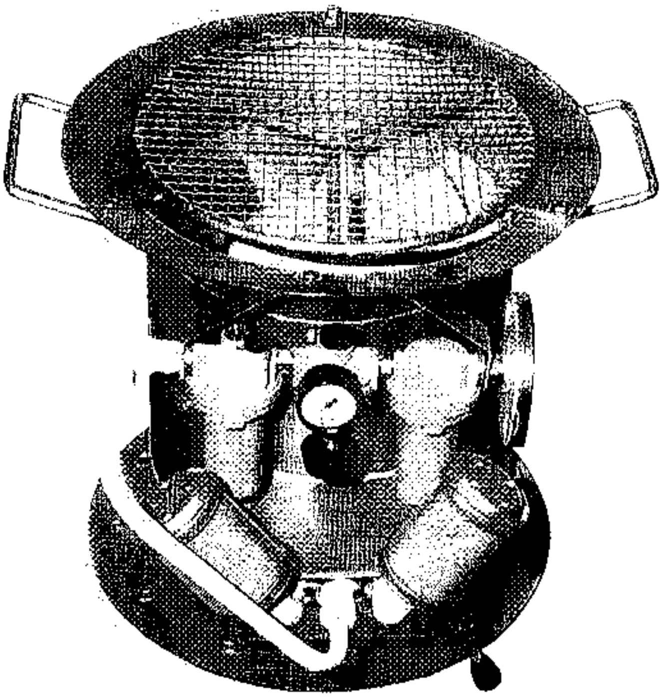

Fig. 4 : Witt & Sohn Works photo.
Axial gas extractor fan for tanks. Compressed air operation in explosion-proof finish, for use on chemical tankers.

Fig. 5 Witt & Sohn Works photo.
Water-powered axial gas extraction fans in explosion-proof design for extraction of air from tanks.

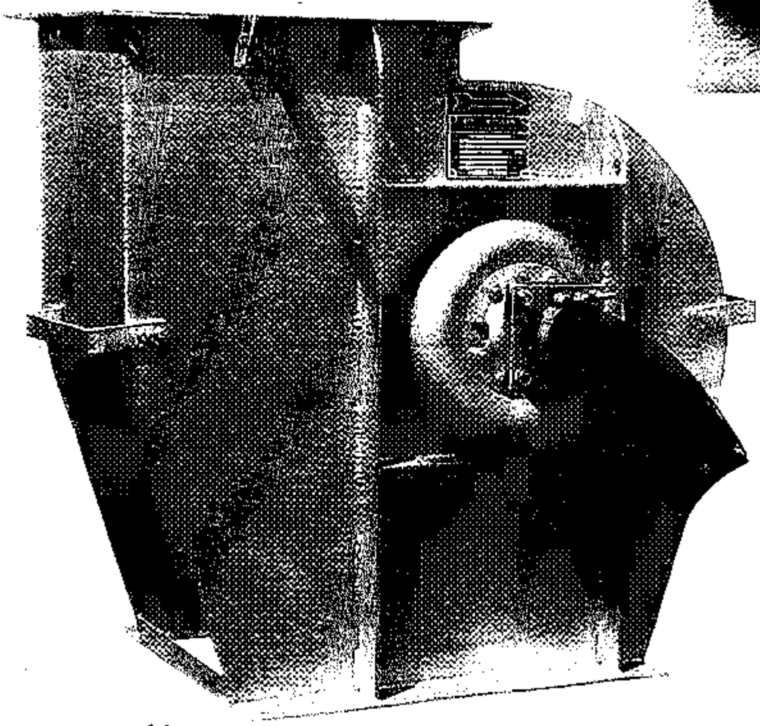

Fig. 6
Witt & Sohn Works photo.
Water-powered radial fan in explosion-proof finish located outside the air current.

9. TEST RESULTS

a) **Plastics**

This term covers a large number of substances built upon hydrocarbons, which can, in turn, be mixed with a large number of the widest range of filling agents and which can have a very wide range of characteristics. Nevertheless, VDMA 24 169 has given general approval to plastic with plastic, plastic with steel and plastic with stainless steel, provided that the build-up of an electrostatic charge can be prevented.

However, KRAVCHENKO [7] and ZALESSKII [8] report cases of ignition with explosive gases, even at low relative speeds in the region of 20 to 30 m/s. The author has not yet had sight of the original reports and this information was gleaned from the report prepared by POWELL [9]. They should, nevertheless, be taken seriously since it is perfectly possible, in theory, to envisage ignition resulting from hot surfaces anywhere, particularly in the case of dusts. In most cases, plastics have poor thermal conductivity properties and this promotes the development of hot surfaces through friction.
Finally, our ancestors were even able to light fires by rubbing pieces of wood together.

It is not known whether or not friction sparks can be generated and this cannot, generally speaking, be ruled out. The glass fibre reinforcement which is often used could play a part here. Particles of plastic which have been torn out could heat up as a result of the deformation work which is done. If the plastic is capable of burning and if the temperature - as in the case of steel particles, is high enough to ignite the plastic particles, there is a high risk of danger.

Plastics should, in fact, only be regarded as being explosion-proof if they have a clearly defined composition with clearly defined fillers and reinforcement inclusions and if tests have demonstrated that this special plastic is explosion-proof. DIN EN 1127 (Draft) prescribes the use of only non-combustible construction materials wherever possible.

b) **Aluminium / Aluminium**

Lightweight metals are often used in pairs by the German mining industry and this means that such pairings have been investigated fairly thoroughly. Unfortunately, there are virtually no investigations from abroad since aluminium can form very high-energy sparks with metal oxides which give off oxygen, particularly with rust or with iron oxide or lead oxide (minium) in paints, and this means that it is basically rejected in many instances. The only reliable and reproducible results relate to aluminium alloys in conjunction with gases, which have ignition energy figures of ≥ 0.07mJ. As usual, the tests were carried out with pure metal surfaces, Table 5. There are no results available for other aluminium alloys. The authors noted that the soft aluminium of the pins heated up quickly and then deformed into a mushroom shape. The temperature was as high as 510°C. According to Table 3, this is high enough to ignite most dusts.

Even this combination of materials, which is probably the safest in terms of gas explosions, cannot, therefore, be classified as absolutely safe if there is dust in the air or if there are coats of paint which give off oxygen. Since the tests were carried out at ambient temperature, higher temperatures as in chapter 7 give cause for concern.

Unfortunately, no information is given for these tests concerning the hardness of the materials, yet aluminium is available in soft, semi-hard and hard forms. The original hardness can be increased during production of the fan by sand-blasting or processing. Higher friction temperatures could also be reached if, instead of the 12mm and 17mm wire pins used in these tests, pins with a larger diameter had been tested.

Fig. 7 shows a fairly old aluminium impeller with severe grinding marks and crushed wire-type strands of aluminium following failure of a bearing, in a machine rated at 40kW. The impeller must have been rubbing against the inlet nozzle unnoticed, with a high contact pressure, for quite some time.

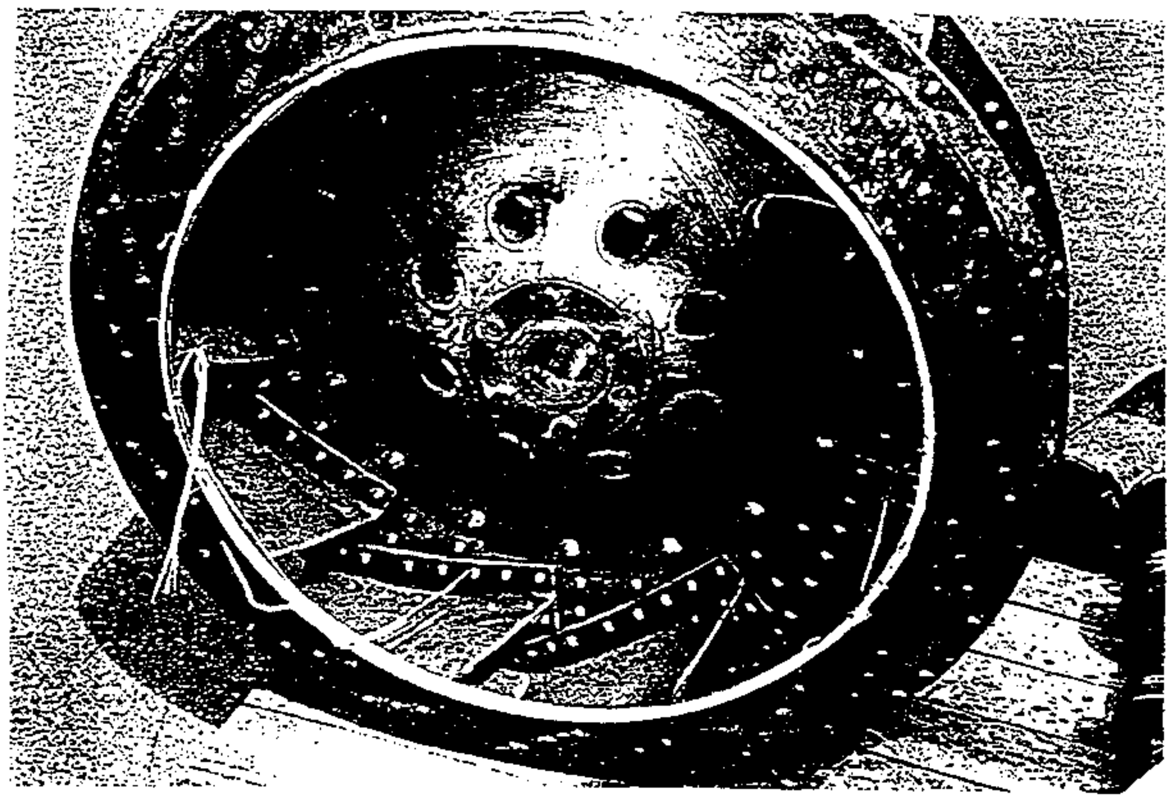

Fig. 7 : An ageing impeller which has been rubbing against the inlet nozzle for a lengthy period following a bearing failure.

		Ignition in gas with ignition energy					
Disk material	**Pin material**	**Methane 0.28mJ**	**Propane 0.25mJ**	**Ethylene 0.07mJ**	u_2 m/s	**Country**	**Source**
AS10GY20	AS13	no	no	no	90,140	France	(11)
G-AlSi9Mg	G-AlSi9Mg	no	no	no	35,70,140	Germany	(10)
G-AlSi12Mg	G-AlSi12Mg	no	no	no	35,70,140	Germany	(10)

Table 5

c) **Aluminium / Brass Alloys**

A number of German tests have been carried out with this alloy - Table 6.

		Ignition in gas with ignition energy					
Disk material	**Pin material**	**Methane 0.28mJ**	**Propane 0.25mJ**	**Ethylene 0.07mJ**	u_2 m/s	**Country**	**Source**
Brass CuZn37	G-AlSi9Mg	no	no	no	35,70,140	Germany	(10)
G-AlSi9Mg	Brass CuZn37	no	no		35,70,140	Germany	(10)
G-AlSi12	Brass CuZn37	no	no	possible	35,70,140	Germany	(10)

Table 6

One or two comments :

Ignition with ethylene occurred only once in 86 tests. In the test in question, the disk had already been roughened by earlier tests and pieces of brass which had been torn off were impressed into the aluminium disk, with the result that the material combination was, in practice, brass with brass and it was this which triggered ignition.

In a margin note, the authors state that where a disk had previously been roughened in tests with sandstone, there was a noticeable increase in the risk of ignition.
Unfortunately, there is no information as to hardness categories here either.

With the thicker 30 x 30mm pins, temperatures of 750°C were reached in the friction zone. The authors classified the risk of ignition as markedly higher than with an aluminium/aluminium combination.

d) **Aluminium / steel**

In the tests relating to Table 7, the authors did not note a single case of ignition. This also applied where the St37 carbon steel was rusty. In these cases, there was intense spark formation solely during a brief transition period at the beginning of the test phase, but this settled down relatively quickly and did not lead to any cases of ignition with ethylene. Despite what appear to be positive results here, the use of aluminium with carbon steel should still be avoided. BARTKNECHT [4] found that the potential for ignition depended essentially on the extent of rusting and, in particular, on moisture. In this correlation, there is a dearth of more detailed information for the tests reported above.

Since steel is a very great deal harder than aluminium, no steel particles were found lodged in the aluminium. In contrast, an aluminium layer built up quickly on the steel with the result that only aluminium surfaces were left rubbing together.

Disk material	Pin material	Ignition in gas with ignition energy Methane 0.28mJ	Propane 0.25mJ	Ethylene 0.07mJ	u_2 m/s	Country	Source
G-AlSi9Mg	SSX5CrNi189	no	no	no	35,70,140	Germany	(10)
G-AlSi9Mg	St37 steel	no	no	no	35,70,140	Germany	(10)

Table 7

As will be seen from Table 7, aluminium and special steel can be classified in the same materials category as aluminium with aluminium. At 500°C, friction temperatures were at practically the same level and this means that the same reservations have to be expressed in terms of the risk of explosion in dust-air mixtures. This pair of materials should not be used on account of the hazards associated with metal oxides which give off oxygen, as was mentioned earlier.

e) **Brass / Brass**

This combination is of virtually no practical importance and is only included for the sake of completeness. See Table 8.

These investigations, most of which were carried out in Great Britain, are based upon English alloys, precise details of which are to be found in the British Standard (Lit. 12).

Susceptibility to explosion was classified as :

None	0 %
possible	up to 10 %
extremely slight	up to 30 %
slight	up to 50 %
very slight	up to 80 %

Lines denote that no tests were reported.

Contact pressure was variable, between 350 and 500N.

In the English tests, the gas mixtures which were used differ somewhat from that which was most prone to ignition; the figures were 7% for methane, 3% for propane and 4% for ethylene. Unfortunately, no details are given of the hardness figures for the alloys which were used, neither is any information given as to the roughness of the disks etc.

These material combinations are not suitable for use. POLLACK and MOHR [10] found high friction temperatures of 760°C, which make it probable, in particular, that there will be a high tendency to ignite where combustible dusts are present. On the basis of Table 3, the temperature was also sufficient to ignite methane and other gases, even though POLLACK and MOHR did not, themselves, observe any cases of ignition.

		Ignition in gas with ignition energy					
Disk material	**Pin material**	**Methane 0.28mJ**	**Propane 0.25mJ**	**Ethylene 0.07mJ**	u_2 m/s	**Country**	**Source**
Aluminium bronze AB 197	Aluminium bronze AB 197	none	extremely slight	slight	46	Great Britain	(11)
Aluminium bronze AB 2	Aluminium bronze AB 2	none	extremely slight	—	46	Great Britain	(11)
Aluminium Bronze AB 2	Aluminium bronze AB 2	—	slight	—	90	Great Britain	(11)
Copper Manganese Al Alloy CM A2	Copper Manganese Al Alloy CM A2	—	none	slight	46	Great Britain	(11)
Copper Manganese Al Alloy CM A2	Copper Manganese Al Alloy CM A2	—	none	very slight	90	Great Britain	(11)
CuZn37	CuZn37	none	none	possible	35,70,140	Germany	(10)

Table 8

Aluminium bronze AB 197, which is little known in Germany, is a roller material containing 10% aluminium and 80% copper by weight. The corresponding figures for the AB 2 cast alloy are 9.5% and 79%. Cast alloy CMA 2 contains 9% aluminium and 72% copper.

f) Steel/brass

This is a combination of great practical significance, since it is recommended in VDMA 24 169 and in other rules. The results are reproduced in Table 9 :

Disk material	**Pin material**	**Methane 0.28mJ**	**Propane 0.25mJ**	**Ethylene 0.07mJ**	u_2 m/s	**Country**	**Source**
Bronze AB 197	St37	possible	slight	—	46	Great Britain	(11)
Bronze AB 2	St37	none	slight	—	46	Great Britain	(11)
Bronze AB 2	St37	none	very slight	—	90	Great Britain	(11)
Copper alloy CMA	St37	none	slight	—	46	Great Britain	(11)
Copper alloy CMA	St37	none	slight	—	90	Great Britain	(11)
Bronze AB197	rusty St37	possible	—	—	46	Great Britain	(11)
Bronze AB2	rusty St37	none	—	—	46	Great Britain	(11)
St37	Bronze AB197	none	slight	slight	46	Great Britain	(11)
St37	Bronze AB2	—	none	slight	46	Great Britain	(11)
St37	Bronze AB2	none	slight	—	90	Great Britain	(11)
St37	Copper alloy CMA2	—	none	slight e	46	Great Britain	(11)
St37	Copper alloy CMA2	—	none	slight	90	Great Britain	(11)
St37	Leaded brass CZ121	—	—	none	46,90	Great Britain	(11)
St37	Naval brass CZ112	—	—	none	90	Great Britain	(11)
St37	Brass CZ106	—	none	very slight	90	Great Britain	(11)
St37	Brass CZ111	—	none	very slight	90	Great Britain	(11)
St37	Copper	—	—	very slight	90	Great Britain	(11)
St37	CuZn39	very slight	—	—	35,70,140	Germany	(10)
CuZn37	X5CrNi189	very slight	—	—	—	Germany	(10)
X5CrNi189	CuZn37	—	—	possible	—	Germany	(10)

Table 9

For comments upon the way in which the tests were carried out, refer to paragraph " e) ". Only the tests with steel disks are of practical importance.

To summarise the findings, the conclusion is that there are only two steel/brass combinations which can be classified as safe : steel/leaded brass CZ121 and steel/naval brass CZ112. The first of these is a 60/40 brass which is common in Great Britain, containing 3% lead. This alloy matches the German CuZn39 Pb3 alloy to a great extent, this having DIN 17 660 material number 2.0401. Naval brass is also a 60/40 brass, but with a 1% tin content. This corresponds with the German CuZn 39 Sn alloy, which has the DIN 17 660 material number 2.0530.

The commonest German brass alloy CuZn37 cannot be classified as ignition-proof. With St37 as the rotating body, ignition occurs very easily at friction temperatures in the region of 900°C and where there is heavy spark formation.
Conditions are somewhat better with special steel. POLLAK and MOHR, however, also classified this combination, which is reported in the final line, as "dubious".

g) Special steel/special steel

POLLAK and MOHR report high friction temperatures in the region of 1000°C, ignition at an early stage and intense spark formation. They classify this combination as being extremely dangerous. The reader is referred to the tests carried out by BARTKNECHT[4], which are reported in Section 7 and which confirm this danger.

It appears highly questionable that this combination is recommended as explosion-proof in VDMA 24 169 and in other regulations. This combination is to be avoided completely.

h) St37 steel/St37 steel

After the tests in paragraph " g) " with special steel, POLLAK and MOHR did not even carry out tests with engineering steel, but one investigation was carried out in England and the results are shown in Table 10.

Disk material	Pin material	Methane 0.28mJ	Propane 0.25mJ	Ethylene 0.07mJ	u_2 m/s	Country	Source
St37	St37	possible	slight	—	46	Great Britain	(11)
St37	St37	possible	very slight	—	90	Great Britain	(11)

Table 10

Even methane, with its relatively high ignition energy, resulted in cases of ignition.

In view of the practical significance of steel and steel as a combination of materials, we will now report in somewhat greater depth upon the investigations carried out by BARTKNECHT [4]. This author carried out thorough investigations with this combination of materials, using the arrangement shown in Fig. 1 to generate friction sparks. The grinding disk was 150mm in diameter, 10mm thick and was rotating at 3000min^{-1}.

The combinations of materials which were investigated are marked with a cross in Table 11.

Pin material	Disk material				
	St37	V2A	St79	1.7131	GGG-70
V2A	X	X	X		
St37	X	X	X		
St79, hardened	X	X	X		
St79, non-hardened	X	X	X		
1.1663	X	X			
1.1654	X	X			
1.1740	X	X			
1.7131				X	
1.2842					X
DIN 17 223 spring steel					X

Table 11 : combinations of materials which were used for ignition tests with steel friction sparks in fuel/air mixtures

The clear conclusion is that all the disk material/pin material combinations marked with an 'X' must be regarded as being likely to cause ignition in hydrogen-air mixtures.

BARTKNECHT noted in particular that V2A disks (1.4301) had the lowest ignition times and the brightest grinding sparks. The opinion that this alloy may be regarded as explosion-proof needs to be revised. Fig. 8 shows clearly that special steel can still cause ignition - even at high hydrogen concentrations, when the oxygen concentration will be low, with a lower tendency to ignite. At the same time, it also shows that the special steel alloy which was used is more dangerous than St37 combined with St37 over wide areas. On the basis of Fig. 8, which reports a host of tests, ignition will always occur within 4 seconds in the case of hydrogen-air mixtures, whatever the steel combination.

It is worth noting that these results were obtained at low relative speeds of 23.6m/s, this being the speed which can be found at the hub of a fan. With a higher contact pressure, faster peripheral speeds and over a longer test period or at a high temperature, ignition is quite conceivable — or even probable — in gas-air mixtures with ignition energy levels which are higher than that of hydrogen-air.

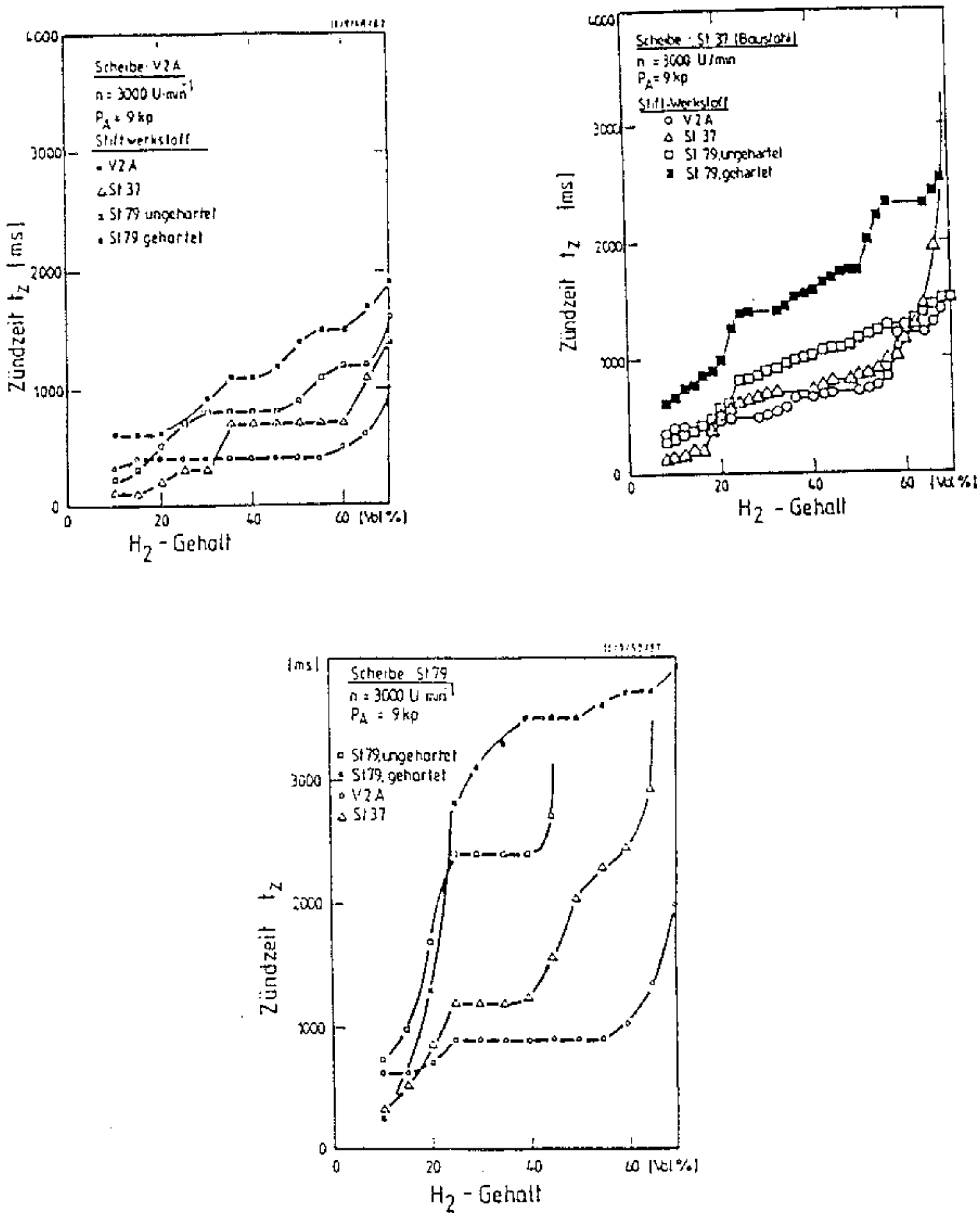

Fig. 8 : Ignition time t_z for steel friction sparks in hydrogen/air mixtures in relation to disk and pin materials - 4mm pins [4]

Baustahl	engineering steel		
Gehalt	content	Stiftwerkstoff	pin material
gehärtet	hardened	ungehärtet	non-hardened
Scheibe	disk	Zündzeit	ignition time

During the course of investigations with butane, propane and methane, explosions occurred under the test conditions which were applied with only two combinations of materials :

- disk in St37/pin in hardened St79 in a butane/air mixture
- disk in V2A/pin in hardened St79 in combination with all the 3 gases listed above.

The low peripheral speed of 23.6 m/s is noteworthy. In fans, relative speeds, i.e. the speed between rotating and stationary parts, can exceed 100m/s. The contact pressure in an actual fan can also be appreciably higher than 9kp ≅ 90N. A word of warning is needed here since, at high temperatures, it must be assumed that there will be ignition even with those pairs of materials with which ignition was not seen in these tests.

<table>
<tr><td colspan="3">Dust type</td><td>Irgawax</td><td>cellulose</td><td>maize starch</td><td>pea meal</td><td>wheat</td><td>Epoxi</td><td>carbon</td></tr>
<tr><td colspan="3">Ignition temperature T_i : [°C]</td><td>330</td><td>350</td><td>400</td><td>420</td><td>450</td><td>460</td><td>500</td></tr>
<tr><td>Disk material</td><td>Pin material</td><td>Pin diameter (mm)</td><td colspan="7">Test result</td></tr>
<tr><td rowspan="6">St37</td><td rowspan="2">V2A</td><td>4</td><td colspan="4">Ignition</td><td colspan="3">No ignition</td></tr>
<tr><td>6</td><td colspan="5">Ignition</td><td colspan="2">No ignition</td></tr>
<tr><td rowspan="2">St37</td><td>4</td><td colspan="3">Ignition</td><td colspan="4">No ignition</td></tr>
<tr><td>6</td><td colspan="7">Ignition</td></tr>
<tr><td>St79 hardened</td><td>4</td><td colspan="2">No ignition</td><td colspan="5"></td></tr>
<tr><td>St79 non-hardened</td><td>4</td><td colspan="2">No ignition</td><td colspan="5"></td></tr>
<tr><td rowspan="5">V2A</td><td rowspan="2">V2A</td><td>4</td><td colspan="4">Ignition</td><td colspan="3">No ignition</td></tr>
<tr><td>6</td><td colspan="5">Ignition</td><td colspan="2">No ignition</td></tr>
<tr><td rowspan="2">St37</td><td>4</td><td colspan="3">Ignition</td><td colspan="4">No ignition</td></tr>
<tr><td>6</td><td colspan="5">Ignition</td><td colspan="2">No ignition</td></tr>
<tr><td>St79 hardened</td><td>4</td><td colspan="2">No ignition</td><td colspan="5"></td></tr>
<tr><td rowspan="8">St79</td><td rowspan="2">V2A</td><td>4</td><td colspan="3">Ignition</td><td colspan="4">No ignition</td></tr>
<tr><td>6</td><td colspan="4">Ignition</td><td colspan="3">No ignition</td></tr>
<tr><td rowspan="2">St37</td><td>4</td><td colspan="7">No ignition</td></tr>
<tr><td>6</td><td colspan="6">Ignition</td><td>No ignition</td></tr>
<tr><td rowspan="2">St79 hardened</td><td>4</td><td colspan="3">No ignition</td><td colspan="4"></td></tr>
<tr><td>6</td><td colspan="3">No ignition</td><td colspan="4"></td></tr>
<tr><td rowspan="2">St79 non-hardened</td><td>4</td><td colspan="3">No ignition</td><td colspan="4"></td></tr>
<tr><td>6</td><td colspan="3">No ignition</td><td colspan="4"></td></tr>
</table>

Table 12 : Ignition effectiveness of hot pin surfaces in dust/air mixtures [4]

i) Ignition tests with organic dusts and with steel/steel

BARTKNECHT also carried out a number of tests with combustible dusts, albeit on a somewhat smaller scale. Wetting sulphur and aluminium dust led to explosions as a result of friction sparks with all the combinations of materials in Table 12. Where other combustible materials were used, Table 12, no cases of ignition occurred as a result of friction sparks during the course of short-lasting tests. Here, however, the peripheral speed was only 24m/s, with a contact pressure of 90N. Over longer-lasting tests, of up to approximately 10 seconds' duration, the dusts which were used showed substantial proneness to ignition due to hot surfaces. There are no results available for tests lasting for longer periods.

Unfortunately, there are no investigations with other commonly found dusts, such as textile dust, wood dust, dye dusts, other plastic dusts and metal dusts. Neither are there any test results with other pairs of metals. The only conclusion which can, therefore, be reached from these tests is that the use of steel with steel should be avoided, whatever the alloy used, where there are combustible dusts.

j) **Metal/sandstone**

POWELL[9], also POLLAK and MOHR[10] carried out tests with various metals which rub against sandstone. They established that engineering steel, aluminium bronze AB197, aluminium bronze AB2, the BS copper-manganese-aluminium alloy CMA2 and aluminium G-AlSi9Mg lead very easily to ignition in methane-air mixtures when rubbed against sandstone. Unfortunately, there are no recent reports available for other metals. In this context, however, the reader is invited to refer to the investigations by DITTMER[18] which were reported in Section 5, on the basis of which it is to be expected that practically all hard metals can generate grinding sparks capable of causing ignition on contact with stones - which practically always contain quartz or flint.

10. SUMMARY OF THE LABORATORY TEST RESULTS

Gas explosions are triggered relatively easily as a result of friction sparks, since these are hot enough, and their relatively low energy content is sufficient, to trigger ignition.

Gas explosions cannot be ruled out in the absence of sparks which are capable of causing ignition. Where a rotor is rubbing against components in the casing, the temperature reached at any hot surface can be high enough to lead to ignition.
It is difficult to cause a dust-air explosion by friction sparks, since the ignition energy required is too high in most cases. Such explosions are caused relatively easily, however, by hot surfaces which are created when two materials rub against one another, since several dust-air mixtures have very low ignition temperatures. Dust deposits appear to be particularly hazardous.

Where a combustible dust is present in a combustible gas-air mixture, ignition can take place with particular ease. At low friction temperatures, it can be started as a dust fire or dust explosion and then draw its main energy from the gas explosion which this ignites.

It is absolutely essential that combustible dusts be kept away from explosion-proof fans unless entirely new metal combinations are being used, which are not described above. Unless this is done, it is only with difficulty that an adequate degree of safety against explosions can be achieved where there are explosive gas-air mixtures present. The friction temperatures of even the safest of the combinations of materials which have been investigated - aluminium/aluminium and steel/special brass, are higher than the ignition temperatures for frequently occurring combustible dusts.

Non-combustible minerals, particularly where these contain quartz, flint or pyrite, have a particularly high potential for danger. Impact sparks with a high energy content occur on contact with the rotor, which has to be manufactured from materials with a high degree of hardness for strength purposes.

Many gases, vapours or mists are far more prone to ignition than are the gases methane, propane and ethylene, with which a particularly large number of investigations was carried out. The question as to whether or not ignition will occur from one case to the next depends on a very large number of factors which lie outside the fan manufacturer's control.

Of all the combinations of materials which were investigated, there were only two with which neither ignition nor sparks which posed the threat of ignition were ever seen in a clean condition at room temperature with ethylene, with the relatively high ignition energy 0.07mJ. These are :

Cast silumin - cast silumin
and
engineering steel - brass alloy CuZn39Sn[4] or CuZn39Pb3.

There are reports of ignition or virtual ignition for all other combinations of materials at normal temperature in ethylene-gas mixtures. This applies in particular to the combinations frequently used hitherto for explosion-proof fans.

Plastic - plastic (at least with some plastics)
Special steel - special steel
Engineering steel - special steel
Engineering steel - engineering steel
Engineering steel - CuZn37 brass.

In cases where temperatures are only slightly raised, less than 100°C, and where contact pressure is high, it is to be feared that even the relatively safe combinations of materials listed above can lead to ignition with gases such as methane, which are relatively difficult to ignite, let alone the dust risk and gases with lower ignition energy or temperature figures. It has yet to be clarified whether the good characteristics are retained after, for instance, the hardening which occurs with processing.

The highest degree of safety, within the meaning of the normative regulations in [1] and [21] calls for the use of new, hitherto uncommon materials.

[4] It is felt that Zu is a misprint in this context.

11. OPERATING EXPERIENCE

Three major explosions, which regrettably claimed several lives, are often described in the Literature:

1) On 10th April 1965, there was an explosion at the Ibbenbühren mine, triggered by a silumin wheel which was grinding against fixed steel components.

2) On 12th June 1975, there was a methane explosion at Houghton Main Colliery, South Yorkshire. This was caused by a fan wheel which was rubbing against the casing. The materials involved were steel rubbing against steel.

3) On 6th September 1955, there was a methane explosion at the Blaenhirwaun Colliery in Carmarthenshire, South Wales. Here, the cause was a fan wheel which was rubbing against a rock, which had found its way into the air duct following blasting. The fan wheel and the casing were manufactured from silumin and the rock was a quartzite.

In addition, the author has been informed of 20 further explosions by Dr. Dyrba[22] and H. Beck[23] and these are reported briefly, in part, in the Appendix. The cause of the damage is not always clearly discernible but the reports do show clearly that there can be several other causes of accidents in addition to friction and impact sparks in adjoining parts of fans.

It is striking that in 7 cases it was metal foreign bodies in the fan which were considered to have been the source of the sparks which caused ignition. With the exception of a single case (a tool which had been left behind) the accidents could have been prevented had there been a rising section of ducting immediately upstream from the fan.

It was often observed that ignition occurred in conjunction with major damage to the fan, such as a blade being torn off, bearing failure or fracturing of the shaft. In many cases, it will have been fatigue in the material, caused by vibration, which will have been the actual cause of the accident. Had a constant watch been maintained for vibration and had temperatures been monitored in the bearings, several of these accidents could definitely have been avoided. The selection of ignition-proof combinations of materials is not, therefore, enough, of itself — albeit that it is an essential requirement — to prevent fan explosions which can have serious consequences.

12. NEW ZONE DIVISIONS and regulations

According to DIN EN 1127 (Draft) dated September 1993[21], areas will in future be divided up in the following manner :

Area	Location in relation to the fan	Occurrence of a hazardous atmosphere due to gases, vapours, mist.
0	normally inside	permanent, long-term or frequent
1	outside or inside	occasionally under normal operating conditions
2	outside or inside	not under normal operating conditions and only short-lasting if occurring thus

Area	Location in relation to the fan	Occurrence of dust clouds	Occurrence of dust coatings
20	normally inside	lasting, long-term or frequent	thickness unknown or excessive
21	outside or inside	occasionally	usually present
22	outside or inside	improbable	present

Table 13 : Diagram showing the new explosion areas.

In the case of gases, the definition of the three risk areas corresponds with those reported in chapter 8. In the case of dusts, the definition is extended and improved.

DIN EN 1127 (Draft) attaches great importance to primary avoidance of atmospheres which can cause explosions, e.g. by replacing hazardous substances or by reducing the quantities in which they are present. Thus, for instance, wherever possible, combustible solvents should be replaced with aqueous solutions. It is also recommended, *inter alia*, that concentrations be restricted, that substances be made inert and that, in the case of dusts, water should be added.

In order to limit the residual risk, it is prescribed that ignition sources be rendered completely inoperative or that the probability of ignition be reduced. The following individual statements are also made, quote:

"In area 2 : ignition sources which can occur constantly or frequently (e.g. when the equipment is operating under normal conditions) are to be avoided;

In area 1 : In addition to the ignition sources listed for area 2, ignition sources which can occur only rarely (e.g. during equipment failures) are to be avoided.

In area 0 : In addition to the ignition sources listed for area 1, even ignition sources which can occur only very rarely (e.g. during rare equipment failures) are also to be avoided.

In area 22: In order to prevent ignition of a dust cloud or of a layer of dust, all ignition sources which are permanent or which occur frequently (e.g. under normal equipment operating conditions) are to be avoided, whilst the temperature of surfaces must also be kept in check in order to prevent ignition of dust deposits.

In area 21: In order to prevent ignition of dust which has been deposited or which has been blown up into the air, even ignition sources which occur rarely (e.g. as a result of equipment failures) are to be avoided as well as those listed for area 22.

In area 20: In order to prevent ignition of dust which has been deposited or which has been blown up into the air, even ignition sources which occur very rarely (e.g. as a result of rare equipment failures) are to be avoided as well as those listed for area 21.

If the explosive atmosphere contains several types of combustible gas, vapour, mist or dust, the protective measures which are selected must be based, as a rule, on the outcome of special investigations.

It will only be permissible for avoidance of effective ignition sources to be the sole protective measure if all types of ignition sources have been identified and if they can be avoided effectively."

The terms "rare" and "very rare" are not defined. Classification also depends upon the consequences of the failure.

Obviously, DIN EN 1127 (Draft) requires that friction, impact and grinding sparks be prevented. The Standard also pays particular attention - and quite rightly so in the author's view - to the potential of hot surfaces as ignition sources. The requirements are set out below in their original wording :

" In area 0, the temperature at the surface of any operating equipment which can come into contact with an explosive atmosphere may not exceed 80% of the ignition temperature, measured in °C, of a combustible gas or of a combustible liquid, even in the event of breakdowns which occur rarely.

In area 1, the temperature at the surface of any operating equipment which can come into contact with an explosive atmosphere may not exceed the ignition temperature of the combustible gas or liquid under normal operating conditions or during breakdowns, but where the gas or vapour can be heated up to its ignition temperature, the temperature at the surface may not exceed 80% of the ignition temperature, measured in °C. This figure may only be exceeded in the event of breakdowns which occur rarely.

In area 2, the temperature at the surface of any operating equipment which can come into contact with an explosive atmosphere may not exceed the minimum ignition temperature for a gas or liquid under normal operating conditions. This figure may only be exceeded during breakdowns and during breakdowns which occur rarely."

The requirements which are designed to prevent dust explosions are even more stringent, these being regarded - and rightly so - as particularly hazardous on account of the low ignition temperatures. The regulations read as follows :

" In area 20, the temperature at any surface which can come into contact with dust clouds may not exceed 2/3rds of the minimum ignition temperature, in °C, for the dust cloud in question; this applies even in rare breakdowns. Furthermore, the temperature at surfaces on which dust can be deposited must be lower by a set safety margin[5)] than the minimum ignition temperature of the thickest layer which can form from the dust in question; this must be ensured, even in cases of breakdowns which occur rarely. If the thickness of the layer is not known, it must be taken to be the greatest thickness which can be envisaged.

In area 21, the temperature at any surface which can come into contact with dust clouds may not exceed 2/3rds of the minimum ignition temperature, in °C, of the dust cloud in question; this applies even in cases of breakdown. Furthermore, the temperature at surfaces on which dust can be deposited must be lower by a set safety margin[5)] than the minimum ignition temperature of the thickest layer which can form from the dust in question; this must be ensured, even in cases of breakdown.

In area 22, the temperature under normal operating conditions at any surface which can come into contact with dust clouds may not exceed 2/3rds of the minimum ignition temperature, in °C, of the dust cloud in question. Furthermore, the temperature at surfaces on which dust can be deposited must be lower by a set safety margin[5)] than the minimum ignition temperature of the thickest layer which can form from the dust in question.

The above temperature ceilings may be exceeded in special cases in all areas, provided that it can be demonstrated that ignition is not expected to occur.

5) A safety margin of 75K is often used between the minimum ignition temperature for a layer of dust and the surface temperature of the operating equipment. This is the figure derived for situations in which the thickness of the dust layer is 5mm or less. It caters for deviations in the minimum ignition temperature measured with a 5mm thick layer of dust, also for the insulating effect of a 5mm layer, which can lead to higher surface temperatures if these are not kept in check.

If the layer thickness is greater than 5mm, different safety margins will be needed, since ignition temperatures for dust layers fall as the thickness increases and since there will be a major insulating effect at work, which can lead to an increase in the temperature at the surface of the operating equipment.

Different safety margins are also necessary in situations where the process air is at a higher temperature than the surrounding air."

These requirements are a great deal more stringent than the requirements laid down to date in VDMA 24 129. In fact, the same temperature limits are set in Part 2 for the prevention of dust explosions, but these apply to normal operations and not for "very rare" (area 20) or "rare" (area 21) ignition sources, such as in the event of breakdowns. These rare or very rare breakdowns must surely include situations in which the rotor begins to grind against a casing component, with a corresponding build-up of hot surfaces as a result. The draft Standard clearly called for these temperatures to be kept in check. In contrast, the VDMA called only for restriction of the risk of ignition due to friction and impact sparks in the case of contact between the rotor and fixed components, which is a possibility which must be taken into account.

The question now has to be put as to whether or not this tightening of the requirements is justified. In the opinion of the author, the answer is definitely in the affirmative. There is no objective reason for randomly excluding one or other of the ignition mechanisms - sparks or hot surfaces.

Only in rare cases do the reported tests contain details of the friction temperatures which were measured. The cases of ignition observed in the tests which have been described were probably ascribed in part to visible sparks, whereas they had actually been triggered by hot surfaces. It was BARTKNECHT (4) who was the first to attempt to differentiate between the ignition mechanisms, see Table 4. Even for aluminium with aluminium, pin temperatures of approximately 510°C were measured by POLLAK and MOHR, even though no cases of ignition were observed. There are no temperature measurements available for steel combined with special brass alloys. The use of these combinations of materials should not, nevertheless, be permitted for most of the gases listed under T1, not, at least, in area 0 or area 1.
In view of their low degree of hardness and/or their low melting temperatures, there were only two materials which could satisfy the requirements of the draft Standard that they should provide a high degree of safety against dust or gas explosions in their role as slip rings[5] used in conjunction with steel or aluminium wheels. These materials are tin, which has a melting temperature of 232°C or lead, which melts at 327°C.

[5] The term *Anschleifring* has not been found in the reference sources and the translation offered relates to *Schleifring*.

Group	Temperature classes											
	T1		T2		T3		T4		T5		T6	
	Substance	ignition temp. C	Substance	ignition temp. C	Substance	ignition temp. C	Substance	ignition temp. C	Substance	ignition temp. °C	Substance	ignition temp. C
II IIA *	acetone	540	i-amyl acetate	380	benzines		acetaldehyde	140				
	ethane	515	n-butane	365	petrol	*						
	ethyl acetate	460	n-butyl alcohol	340	special benzines	*						
	ethyl chloride	510	cyclohexenone	430	diesel fuels	*						
	ammonia gas	630	1,2-		heating oils	*						
	benzene	555	dichloroethane	440	n-hexane	240						
	acetic acid	485	acetic acid									
	carbon monoxide	605	anhydride	330								
	methane	595										
	methanol	455										
	methyl chloride	625										
	naphthalene	520										
	phenol	595										
	propane	470										
	toluene	535										
II IIB *	mains gas (lighting gas)	560	ethyl alcohol	425	hydrogen sulphide	270	ethyl ether	180				
			ethylene	425								
			ethylene oxide	440								
II IIC *	hydrogen	560	acetylene	305							carbon bisulphide	95

* The ignition temperature depends upon the composition and is between 220 and 300°C, in special cases higher than 300°C.
* Sub-divisions IIA, IIB and IIC do not apply to electrical equipment in the ignition-proofing category "Increased safety" but only for "Pressure-proof casing"

Table 14 : Illustrations for the classification of combustible gases and vapours EN 50 014

These melting temperatures are below the ignition temperature of any, or virtually any of the gases or dusts which occur frequently, with the result that the slip ring will melt away before the ignition temperature can be reached, with the required thermal safety margins being respected. The material of choice from an environmental point of view is tin, despite the fact that it is more expensive. Pure zinc is also of interest, as are tin alloys, as a less expensive alternative, with their low melting points. With a melting point of 419°C, however, the figure for zinc is higher than the threshold temperature (ignition temperature and safety add-ons) for some dusts and gases and the material itself is harder. Unfortunately, there are no experimental results yet available with these materials.

One practical option when selecting reliable pairs of materials in pure gases would be to follow temperature categories T1 to T6, Table 14, which are valid in EN 50 014 for explosion-proof motors. For some of the gases in T1, zinc would suffice as a protective strip, but tin would need to be used for other gases in T1 and for all gases in T2-T6.

Corrosion is not seen as a problem where tin or zinc is used in conjunction with coated engineering steels, particularly where the latter are galvanised or treated with a coating of zinc powder.

It would appear to be beneficial if the fixed part involved in the grinding process is as soft as possible. This restricts the amount of friction energy since the soft component in the friction process deforms rapidly under the contact pressure, even if the melting point has yet to be reached.

Surface temperature requirements in the new draft Standard may be deemed to have been met in the cases of most gases if, in addition to design features intended to avoid contact between the rotor and fixed parts, the equipment also features the following combinations of materials. Where steel is concerned here, there appear to be no restrictions as to what alloy is used (Table 15).

Area	T1 - T2	T3 - T6	Comments
0	Tin / steel or Zinc / steel 1)	Tin / steel 2)	1) Only for gases with ignition temperatures higher than 500°C 2) The regulations are not satisfied. The use of fans should be avoided unless this would, in itself, create a greater risk.
1	Tin / steel or Zinc / steel 1)	Tin / steel 2)	
2	Tin / steel or Zinc / steel 1)	Tin / steel	

Table 15 : Recommended combinations of materials in gases, vapours, mists

There is no standardised ignition temperature table, of the type shown in Table 14, in respect of dusts. If we take the test results obtained by BARTKNECHT[4], we could divide these up into, say, three ignition classes. Table 16. There seems to be little purpose in dividing these up into finer categories since there is still a great deal of uncertainty about ignition temperatures. In any case, the table would have to be checked and extended.

With a combination of tin and steel, a surface temperature can be achieved which, in respect of class Ta dusts, is lower than 2/3rds of the ignition temperature minus the 75K safety margin. For class Tb dusts, the surface temperature is kept to a maximum of 2/3rds of the ignition temperature with tin/steel. Dust deposits must, therefore, be avoided, since the thermal safety margin cannot be maintained.

For class Tc dusts, tin and steel give a surface temperature which is, in fact, below the normal ignition temperature for the dusts listed here, but the 2/3rds safety factor and the 75K safety margin cannot be maintained.

Tables 15 to 17 should be regarded as a first draft. The requirements of the Standard are not met in all cases, even where tin is used, with its low melting temperature.

In view of the small amount of tin needed to act as a protective strip in any given instance, prices can be kept in check; neither is there any problem in obtaining tin in sheet form. It is important that protective strip rings[6] be fitted at the best possible location and that care be taken to see to it that they are thick enough. In Fig. 9, the protective strip ring a) between the impeller and the casing should have the smallest possible diameter. which minimises relative speeds and, hence, friction temperature and wear.

At the same time, the thickness should be no less than 3mm, with a width of at least 30mm. The intake slip ring (b), on the other hand, may be thin, provided that it is sufficiently broad, e.g. at least 10% of the diameter of the impeller.

Ta		Tb		Tc	
Pea meal	430°C	Cellulose	350°C	Wetting sulphur	270°C
Slurry	430°C	Lycopodium	370°C	Irgawax	330°C
Wheat dust	450°C	Soya meal	380°C		
Epoxi	460°C	Maize starch	400°C		
Theophylline	470°C	Lactose	400°C		
Orasol red	500°C	PE dust	420°C		
Aluminium	500°C	Lignocel	420°C		
Saar coal	550°C				
Other dusts $T_z \geq 425°C$		Other dusts $T_z \geq 350°C < 425°C$		Other dusts $T_z < 350°C$	

Table 16 : Ignition temperatures as per [4] divided into 3 dust ignition classes, Ta, Tb, Tc.

Area	Ta	Tb	Tc	Comment
20	Tin/steel 1)	Tin/steel 2)	Tin/steel 3)	1) The requirements are met, even where there is a build-up of dust 2) A build up of dust is not permitted 3) The temperature is below the ignition temperature but safety add-ons are less than required
21	Tin/steel	Tin/steel	Tin/steel	
22	Tin/steel	Tin/steel	Tin/steel	

Table 17 : Recommended combinations of materials - dusts

(6) A literal translation of *Streifschutzring* would be '...strip protection ring...'

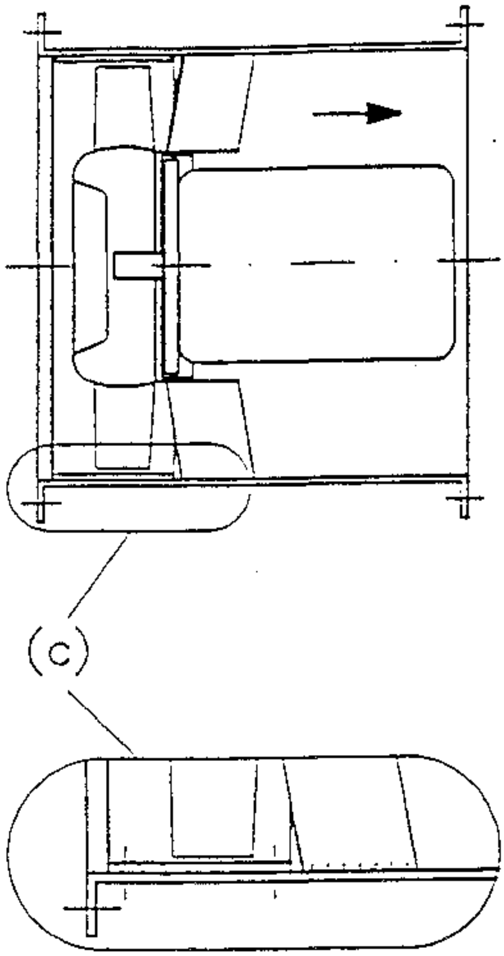

Fig. 9 : Schematic diagram of the protective strip (shaded) in axial fans

In axial fans, Fig. 9, the protective strip ring can only be fitted in the area where the relative speed is highest and it should, therefore, have an adequate minimum thickness, for instance 3mm. Care must obviously be taken whenever one is dealing with protective strip rings to ensure that there are no rivets or screws made from harder materials in the area where grinding is anticipated. Details are to be laid down in the product Standards, which have yet to be compiled.

Where tin is suggested in areas 2 and 22, zinc may possibly be used instead.

In order to avoid the risk of unpleasant surprises, it would help in the short-term to conduct tests to confirm that tin and zinc are suitable products for use here.

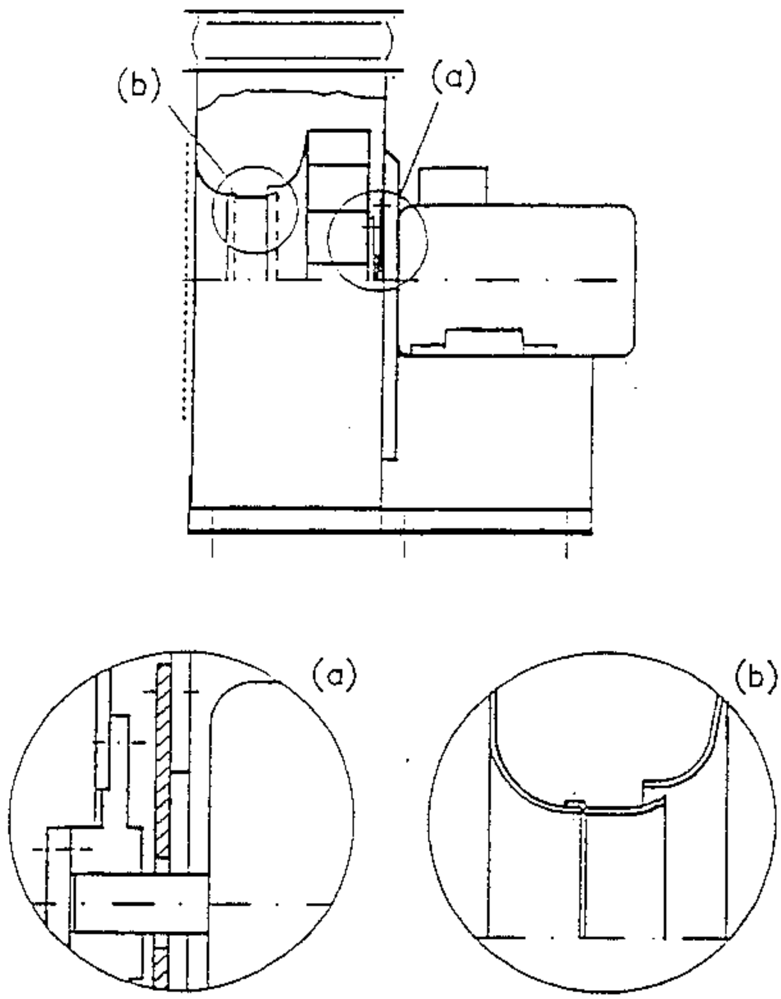

Fig. 10 : Schematic diagram of the protective strip (shaded) in radial fans

12. CONCLUSION

Improved protection against explosions in fans needs to be based upon a five-pronged approach:

1. Action at the design stage to ensure, as far as possible, that rotating and fixed components do not, first and foremost, come into contact with one another.
2. A protective strip to prevent ignition in the event that rotating and fixed components do, in fact, come into contact with one another.
3. Regular cleaning.
4. A rising gradient upstream from the fan.
5. Vibration and bearing temperature monitoring.

Each of these conditions must be satisfied. None of them is able alone to exclude explosions. Point 1 is covered comprehensively in VDMA 24 169. Safety clearances are laid down between rotating and fixed components. These appear to be adequate and can be incorporated as they are into a new Standard.

Once the fan has left the manufacturer's works, the critical clearances can, however, be altered significantly as a result of transport, installation, tension in the V-belt, bearing replacement, wear or other factors, yet this can go completely unnoticed. As a rule, it is practically impossible to check the safety clearances, e.g. in Figs. 9 and 10, once the fan has been installed. Even where parts begin to grind together, this can go unheard in places where there is a great deal of noise and this means that protection against explosions can never be based solely upon the expectation that there will be no contact between rotating and fixed components. An effective protective strip would seem to be absolutely essential.

As for the protective strip, the combinations of materials permitted in the VDMA cannot, in many instances, be relied upon to prevent explosions, as will be seen from the tests quoted in this paper. There appears to be a need for improvements to VDMA 24 169 in this area.

In order to improve safety in terms of grinding action, it should also be stated in the VDMA that the use of clamping sleeves to secure shafts is not permitted, since these sleeves can cause the shaft to wander about.

Care must be taken to ensure that no foreign bodies, particularly quartz, flint, pyrite or metal, find their way into the fan. This can be achieved by putting a section with a rising gradient immediately upstream from the fan.

Since it is frequently the case that explosion-proof fans are called upon to work for long periods without supervision, some thought should be given to the question as to whether or not it should be compulsory to install a vibration and bearing temperature monitoring system which would be capable, at least to some extent, of shutting the fan down automatically if any of the failures which can be envisaged should occur.

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Prof. Witt/cb
Pinneberg, 07.04.1994

APPENDIX

Explosion damage triggered by fans

[22] and [23] describe the following accidents :

TIMBER/ TIMBER PRODUCTS

1. Chipboard Manufacture - Surface Drying Equipment

There was an explosion in the surface drying plant, closely followed by a second explosion. The plant was shut down using the emergency stop facility. A fire was spotted in the separator and this was then tackled. When the inspection hatch on the circulating air fan was opened (approximately 1 hour after the explosion) a smouldering spot was seen sticking to the fan casing. It proved impossible to determine the cause of ignition. Gas was circulating under heavy inertial action[7] and the temperatures which were reached (drier, inlet and outlet temperatures) were normal for surfacing operations.

Damage :	Property damage
Ignition source :	not known
Year :	1969, North Germany

2. Joinery Workshop - Central Dust Extraction

There was no separator in the central dust extractor, with the result that fairly sizeable pieces of wood found their way into the blades in the fan, thereby damaging them. A part of a blade which had broken off rubbed against the exhauster casing, causing heavy sparking which ignited the dust/air mixture which was being drawn through (part of which was sanding dust). This was followed by two further serious explosions in the joinery workshop, since dust which had been deposited on beams, mouldings and other such items was thrown up into the air where it ignited.

Damage :	Joinery workshop completely destroyed
Ignition source :	mechanical sparks
Year :	1953

3. Grinding Shop - Extraction

There was a primary explosion inside a bunker used to collect grinding dust, which was bagged and stored. Since this bunker is completely surrounded by working areas, fire spread through the relief surfaces which responded (access doorway and other areas amounting to 2m²) into

[7] The term *inertisierung* has not been found in the reference sources and it is not clear what is meant here.

adjoining areas, completely destroying the premises. There was severe deformation in one of the fans, from which it may be assumed that pieces of metal had found their way into the extraction system, where they caused sparks which ignited the explosive dust/air mixture.

Damage :	Property damage, approx. DM 5m
Ignition source :	suspected to have been mechanical sparks
Year :	1979, North Rhine Westphalia

4. Wood Dust Works - Extraction/Filter Chamber

The head of one of the screws in the fan casing broke off and this caused a wood dust/air mixture to ignite. The explosion destroyed the rotary piston blower, the pressurised duct filtration plant and the filter room.

Damage :	Property damage - approx. DM 36,000
Ignition source :	mechanical sparks
Year :	1967

5. Wood Dust Works - Filtration Plant

Following damage to a bearing, the fan shaft was left at an angle, with the result that the blade struck the casing, causing sparks. The result was a dust explosion which led to a fire in the filter.

Ignition source :	mechanical sparks
Year :	1972

FOOD INDUSTRY and ANIMAL FEEDS

6. Chocolate Moulding Shop - Cooling Fan

Maize starch powder was used in moulding filled chocolates. A piece of Pertinax in a cooling fan became electrostatically charged. Sparks caused when this discharged triggered the dust explosion.

Ignition source :	electrostatic discharge
Year :	1967

METALS

7. Grinding Shops - Extractor Plant

Dust generated during polishing of bobbins was drawn off by means of an extractor plant. Foreign bodies which had found their way into the fan caused sparks on a blade, which led to an explosion and a fire outbreak.

Damage :	2 persons injured, property damage valued at approx. DM 10,000.
Ignition source :	mechanical sparks
Year :	1977, North Rhine Westphalia

8. Grinding Shops - Extractor Plant

Unusual noises (a slight rattle) were heard in the extractor plant so this was shut down and checked. The inspection yielded nothing to suggest that anything was wrong. Immediately after the equipment had been switched on again there was a violent explosion which spread along the ducting system to workplaces. The separators showed no signs of pressure damage. Examination of the fan revealed that a blade had broken off, whilst the remaining blades were bent. It is suspected that a tool (door latch) became wedged in the fan and that this caused sparks when the equipment was switched on again.

Damage :	2 persons killed. 3 injured, property damage valued at approx. DM 40,000.
Ignition source :	mechanical sparks
Year :	1978, North Rhine Westphalia

9. Grinding Shops - Extractor

As a result of a fracture to its spindle, a ventilation hatch fell into the fan which was located beneath it, causing severe mechanical vibration and generating impact sparks. In addition, there was a moisture separator[a] which was not working properly and this had led to an accumulation of dust on the outlet side of the fan. This dust was then blown into the air, creating a combustible dust/air mixture. The primary explosion in the region of the fan was in the back-flow air duct, where a considerable quantity of dust had accumulated. This was then forced out into the grinding shops, where there was a severe explosion within a confined area.

Damage :	8 persons killed, substantial property damage
Ignition source :	mechanical sparks
Year :	1979, North Rhine Westphalia

(a) Literally a 'wet separator'

10. Grinding and Polishing Shops - Extraction

A fan blade which had broken off generated impact sparks and these led to an explosion in the separator, which was located outside the working area. A wall of flame then travelled through the ducting system into the working area, where a fire broke out, causing burns.

Damage :	1 person injured, property damage valued at approx. DM 30,000.
Ignition source :	mechanical sparks
Year :	1977, North Rhine Westphalia

11. Sheet Aluminium Rolling Works - Brushing Machine

During cleaning operations which were being carried out on a brushing machine, aluminium dust which had accumulated in a dead angle was fed[9] into the extractor pipework, which was in operation at the time, thereby causing an aluminium dust explosion. A nut which had found its way into the extractor system generated sparks when it came into contact with the blades in the fan and it was this which ignited the aluminum dust/air mixture.

Damage :	3 persons injured, substantial property damage
Ignition source :	mechanical sparks
Year :	1963

12. Vacuum Melting Process - Extraction for Cleaning

After a vaporisation process under vacuum conditions, the metal coatings which had condensed onto the walls of the boiler (predominantly aluminium) were removed by means of hand-held brooms and flexible suction equipment, consisting of a metal hose and a fan which vented to the open air. There was no provision for separation of the small amount of dust which was generated and this had been the practice for at least 10 years. It appears that a foreign body was sucked into the fan and that this caused the sparks which triggered the explosion.

Damage :	1 person injured
Ignition source :	probably mechanical sparks
Year :	1979, Bavaria

[9] Literally '...was turned into...'

13. Grinding Shops - Extractor

Dust was removed from workplaces via a fan installed at the end of a collector duct, this fan venting into the open air. For reasons which are not known, there was an explosion in the region of the fan and this caused extensive damage on account of the fact that dust had been allowed to accumulate unnoticed in the ducting.

Damage :	Property damage
Ignition source :	not known
Year :	1978, North Rhine Westphalia

14. Preparation Operations - Extractor

Whilst repair work was being carried out on a cyclone separator, there was an explosion, the effects of which travelled into parts of the plant located upstream. This led to the destruction of the production shops. A screwdriver had been left accidentally in the fan casing and when the fan was switched on for testing purposes this generated mechanical sparks which ignited the dust which had been blown into the air at the same time from the deposits which had formed.

Damage :	2 persons injured, substantial property damage
Ignition source :	mechanical sparks
Year :	1985, North Rhine Westphalia

15. Surface Preparation - De-polishing Machine

New steel brushes were being fitted[10] in the plant. Once this repair work had been completed, the operator switched the extractor fan installed on the crude gas side of the moisture separator back on. Shortly afterwards, there was an explosion in the ducting system, followed by a fire. It is assumed that a foreign body or bodies had caused sparks in the fan, thus allowing a hybrid mixture to be ignited. What probably happened is that the arrangements for drawing off the hydrogen which had been generated in the sludge tank during a fairly lengthy shut-down had been inadequate, with the result that the gas had been able spread out into the ducting system.

Damage :	1 person injured, property damage valued at approx. DM 300,000.
Ignition source :	mechanical sparks
Year :	1981, Rhineland Pfalz

[10] It is assumed that the verb should read *eingesetzt*

16. Filter(s)

A broken blower shaft led to the generation of impact sparks which caused an explosion in the filter. There were blow-outs to three extraction points and these led to fire outbreaks.

Damage :	Property damage valued at approx. DM 100,000.
Ignition source :	mechanical sparks
Year :	1977

CHEMICALS

17. Explosion of Propellant Deposits in an Extractor Plant

Unf. Ber. BG Chemie 34/86(34) - 10.09.1986

BG Chemie Accident Report - Extractor, mechanical filter, explosive explosion, propellant

In preparation for testing of materials, two workers were cutting a propellant charge into disks and then into strips under safe conditions. The dust and chips which were generated were sucked though a pipe into the adjacent precipitator building. Once the job had been done, both workers switched off the suction blower located outside the precipitation plant. As a result of a detonation, one of the two workers suffered slight burns and injuries whilst the other sustained a shock. Since propellant powder was being processed and since this is relatively sensitive to friction due to its boron content, it must be assumed that propellant residue was thrown off by the paddle wheel (which was slightly out of balance) and ignited by friction in the process. The explosion-type detonation ran from the clean gas side through the moisture separator into the coarse gas ducting and back into the working area. Despite the fact that there was a moisture separator, floating dust formed from the explosive material had obviously been finding its way into the clean gas side over the course of the years and ignition had then occurred on the clean gas side.

Damage :	2 persons injured, property damage
Ignition source :	dust explosion

18. Severe Burns in a Fire at a Plant used to Manufacture Collodion Wool Chips

Unf. Ber. BG Chemie 8/86 (20) - 27.06.1985

BG Chemie Accident Report, Fire, nitrocellulose powder, friction, burns, fire protection.

During the manufacture of collodion[11] wool chips, a fire breaks out in the area around the drier. A prime measure of the severity of the fire is provided by the fact that the drums in the empties store were completely consumed. One worker suffered severe burns in this fire. It is suspected that ignition occurred in the area around the drier as a result of contact between a fan blade and the wall of the casing; it is probable that the fire was helped to spread by substantial quantities of nitrocellulose dust in the filling area. When it came to re-building the plant, one requirement was that totally new fire prevention arrangements be included in the design, featuring a deluging system of adequate proportions.

Damage : 1 person seriously injured, property damage
Ignition source : friction sparks

19. Explosion in Extraction Plant

There was a violent explosion in the extraction building of an oil mill. In this building, pre-crushed oil-seeds were sprayed with hexane, heated to a temperature of 50°C, inside sealed extraction equipment, a process which flushed the oil out. This extraction process generated both liquids and solids.

After a batch had been passed through, the extractor was opened, allowing hexane to escape into the surrounding area. The vapours were extracted by 2 exhausters, each with an hourly capacity of 10,000m^3. There was a violent explosion.

Walls of flame travelled outwards ⌊ from the extraction area ⌋, killing two employees outside and causing shock, bruising and lacerations to four other employees who did, however, survive.

The TÜV inspector assumed that a shaft in one of the 10,000m^3 per hour exhausters ventilating the extraction area had been running hot, but it is just as probable that this exhauster did not begin to run hot until it had sucked in hot combustion gases.

Even though criminal investigations into this case have yet to be completed, it is highly unlikely that anything of significance will be learned from the findings.

Damage : 2 persons killed, 4 injured, property damage
Ignition source : probably bearing damage

[11] No definition has been found for *Collodium* in the German-language reference sources, but it is assumed that the noun is being used in its Latin form.

20. Explosion in Storage Tanks containing Vinyl Chloride

At a chemical works, vinyl chloride was escaping through a leaking slide valve from a 15m long tank with a diameter of 3m, one of 7 at the site. The leaking vinyl chloride formed an explosive mist with air and spread out, igniting on the premises of a neighbouring company, probably in a "hot fan". One of the tanks exploded, was ripped from its fastenings, carried 500m through the air, destroyed the boiler house and swept the water tank for a further distance of 100m. A second tank flew 650m into a field. The remaining tanks were ripped open and burned out.

The fire could not be extinguished. With the support of several industrial fire-fighting units and specialists, the city Fire Brigade was endeavouring to put out fires which had also broken out on surrounding premises. This proved difficult since the power and water supplies had been cut. In addition, whilst the fire was burning natural gas was escaping from the damaged main feeding the boiler house (6bar, Ø 4"), but this did not ignite. It took quite a while to cap this main, since it could have been in the path of any other tank which might have exploded.

The state gas supplier's main isolating valve was approximately 3km away and it proved impossible completely to shut off the gas supply using the slide valves installed at that point. Fire-fighting efforts were helped by rain, since this did, to some extent, diminish the effects of intense heat radiation and it did keep surrounding buildings and parklands damp. However, the rain did precipitate pitch black clouds of chloride-laden smoke which were drifting away over the town, a process which resulted in the formation of hydrochloric acid, causing extensive damage.

A major motor manufacturer has an assembly plant some 15km from the site of the fire; the chrome parts on some 5000 brand new cars were damaged by corrosion at this plant. It was only prompt action in washing all the vehicles which meant that only the paintwork of light-coloured vehicles was damaged. Such losses placed a very heavy burden on the affected parties since none of the business affected carried insurance which covered such an event. The chemicals company which caused the accident did, of course, have third-party liability insurance, but the extent of cover was nowhere near sufficient to deal with all the damage caused by the accident, since the sum insured amounted only to around a fifth of the value of the claims which were filed.

Damage :	extensive property damage
Ignition source :	a "hot fan" situated outside an area 0 which was too small.

DYE TREATMENT

21. Explosion in Sulphur Deposits

Work at an oil refinery constantly generates a substantial quantity of sulphur in liquid form. This is dropped onto conveyor belts, where it cools down and sets. The solid sulphur is then bagged.

There is an extractor plant which removes sulphur dust from the air; this had precipitated in the fan (45kW) and in the ducting, causing significant imbalances in the impeller in the process. The plant was cleaned at regular intervals. The special steel impeller, which was attached to the motor shaft by means of a 'Fenner'[12] hub, became detached and struck the engineering steel casing. There was a powerful explosion, which spread through the ducting network. The effects of the explosion were contained effectively by the special relief and reflection equipment which was installed.

Damage : Property damage
Ignition source : contact between the impeller and the casing
Year : 1994, Lower Saxony

22. Fire in Paintshops

Vehicle paintshops were fitted with under-floor extraction. The ceiling-mounted extractor fan drew the paint mist through filters and out into the open air. Warm fresh air was fed in by means of a second fan.

A fire broke out in the fan (3kW) after work had finished, whilst only the air-feed fan was still switched on, the extractor fan free-wheeling in the air current. There was a heavy coating of paint residue on the inside of the fan. It was assumed that this fire, which had developed very slowly, had started before the extractor fan had been switched off, as the sticky wheel rubbed against the sticky wall of the casing.

Damage : Property damage
Ignition source : friction
Year : 1983, Austria

[12] 'Fenner' is believed to be a proprietary name.

23. Fire in Paintshops

An explosive fire broke out in a fan fitted in the evaporation wall[13] located in motor vehicle paintshops fitted with the latest equipment. Two of the staff who were present saw the fire start in the fan, but they were able to get to safety, despite the explosive manner in which the fire spread.

The fan had a 'Fenner' hub which had worked loose on the shaft, with the result that the retaining disk on the wheel began to grind against the wall of the casing. Ignition probably occurred as a result of friction or impact sparks. One possibility which cannot be ruled out completely is that a missing hub screw was thrown out, generating impact sparks in the process.

Damage :	Property damage
Ignition source :	friction
Year :	1993, Austria

Prof. Witt/cb
Pinneberg, 03.05.1994

[13] The term *Abdunstwand* has not been found in any of the reference sources. The component *Dunst* suggests '...fumes, vapour or haze...', whilst *Wand* is us translated as '...wall...' The German *Abdunstzeit* is translated as '...flash time...'