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(54) Electrical apparatus employing a gaseous dielectric.

(57) An improved electrical apparatus employing a gaseous dielectric is disclosed. The improvement resides in the composition of the gaseous dielectric, which comprises a mixture of approximately 60 - 99.5 mole % of SF_6 and approximately 0.5 - 40 mole % of a fluorocarbon compound having no unsaturated carbon bonds. Preferred fluorocarbon compounds are C_2F_5CN, $CBrClF_2$, and $c\text{-}C_4F_8$. The gaseous dielectric has a higher dielectric strength than SF_6 alone and greatly suppresses formation of carbon powder during arcing.

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ELECTRICAL APPARATUS EMPLOYING A GASEOUS DIELECTRIC

The present invention relates in general to electrical apparatuses which employ a gaseous dielectric, and in particular to an improved electrical apparatus employing a novel gaseous dielectric which has a high dielectric strength and which forms only a small amount of carbon at the time of arcing.

In electrical equipment of the type comprising a sealed chamber, a gaseous dielectric which fills the chamber, a conductor disposed inside the chamber, and a solid insulating member which supports the conductor, it is common to use sulfur hexafluoride (SF_6), which has excellent dielectric properties, as the gaseous dielectric. In order to achieve further reductions in the size of this type of electrical equipment, there is a need for a gaseous dielectric having a higher dielectric strength than SF_6. However, there has yet to be found a gas having suitable properties. For example, while C_2F_5CN (1.8 times the dielectric strength of SF_6), $CBrClF_2$ (1.4 times the dielectric strength of SF_6), and $c\text{-}C_4F_8$ (1.4 times the dielectric strength of SF_6) are all excellent from the standpoint of dielectric strength, they can not be applied alone as gaseous dielectrics in electrical equipment

in which arcing takes place, since they form electrically-conducting carbon powder during arcing.

In a paper entitled "Ternary Gas Dielectrics" (The Third International Symposium on Gaseous Dielectrics, 1982, Document No. 15), I.G. Christophorou et al. disclosed a gaseous dielectric comprising a mixture of SF_6 and 2-C_4F_8 (octofluorobutene) which has a high dielectric strength but which forms a powder during arcing consisting of a nonconducting powder and a conducting powder. Figure 1 shows test results published in the above-mentioned paper for arcing tests using aluminum electrodes in gas mixtures consisting of SF_6 and 2-C_4F_8. The amount and the content of the powder formed during arcing clearly depend on the mole % of 2-C_4F_8 in the gas mixture. When the gas mixture consisted of 100% SF_6, the powder which was formed consisted of AlF_3. However, at greater than 20 mole % 2-C_4F_8, the content of the powder greatly changed and the powder began to consist of increasing amounts of carbon powder. Thus, although a mixture of SF_6 and 2-C_4F_8 has a higher dielectric strength than SF_6 alone, it still has the drawback that it forms too large a quantity of conducting powder.

It is the object of the present invention to provide an improved electrical apparatus which utilizes a gaseous dielectric which has a higher dielectric strength

than SF_6 and which forms only a small amount of carbon powder at the time of arcing.

An improved electrical apparatus according to the present invention is of the type comprising a sealed chamber filled with a gaseous dielectric, an electrical conductor disposed in the chamber, and a solid electrically-insulating member which supports the electrical conductor. The improvement resides in the composition of the gaseous dielectric, which comprises a mixture of SF_6 and a saturated fluorocarbon compound, i.e. a fluorocarbon compound having no unsaturated carbon bonds. The amount of SF_6 in the gaseous dielectric is approximately 60 - 99.5 mole % and the amount of the fluorocarbon compound is approximately 0.5 - 40 mole %. Preferred substances for use as the fluorocarbon compound are C_2F_5CN, $CBrClF_2$, and $c\text{-}C_4F_8$.

Figure 1 is a graph of the amount of powder formed at the time of arcing as a function of the mole % of SF_6 in a gaseous dielectric comprising a mixture of SF_6 and $2\text{-}C_4F_8$.

Figure 2 is a schematic illustration of an improved electrical apparatus according to the present invention.

Figure 3 is a chart of the amount of carbon powder formed during arcing tests performed in SF_6 and in various fluorocarbon compounds.

Figure 4 is a graph of the amount of carbon powder formed at the time of arcing plotted as a function of the composition of a gaseous dielectric comprising a mixture of SF_6 and C_2F_5CN.

Figure 5 is a graph of the AC breakdown voltage plotted as a function of electrode separation for various mixtures of SF_6 and C_2F_5CN.

Figure 6 is a schematic representation of the electrodes used to obtain the data of Figure 5.

Figure 7 is a graph of the relationship between (the amount of powder formed at the time of arcing / the length of time for which an arc was sustained) and arc current for two different gaseous dielectrics, one comprising 100% C_2F_5CN and the other comprising a mixture of 25 mole % of C_2F_5CN and 75 mole % of SF_6.

An embodiment of an improved electrical apparatus employing a gaseous dielectric will now be described while referring to Figure 2 of the accompanying drawings. In the figure, element number 1 is a sealed chamber filled with a gaseous dielectric 2. Elements number 3 are bushings electrically connected to disconnecting switches 4. Element

number 5 is a circuit breaker electrically connected to the disconnecting switches 4 by electrical conductors 6.

The novel feature of this apparatus is the composition of the gaseous dielectric 2. It comprises approximately 60 - 99.5 mole % of SF_6 and approximately 0.5 - 40 mole % of a saturated fluorocarbon compound. Preferred substances for use as the fluorocarbon compound are C_2F_5CN, $CBrClF_2$, and $c\text{-}C_4F_8$.

In the above-described prior art, a mixture of SF_6 with an unsaturated fluorocarbon ($2\text{-}C_4F_8$) had the disadvantage that too large a quantity of carbon powder was formed during arcing. The present inventors found that if a saturated fluorocarbon is used instead, the amount of carbon powder formed can be greatly decreased.

To illustrate this fact, the present inventors performed arcing experiments in various saturated and unsaturated fluorocarbon compounds in gaseous form sealed at atmospheric pressure in a 2-liter container using a discharge voltage of 30kv. The amount of carbon powder formed (mg) for each gas is plotted in Figure 3. As can be seen from the figure, saturated fluorocarbon compounds such as C_2F_5CN, $CBrClF_2$, and $c\text{-}C_4F_8$ formed much less carbon powder than unsaturated fluorocarbon compounds such as $1,3\text{-}C_4F_6$, $c\text{-}C_4F_6$, and $2\text{-}C_4F_6$.

In order to determine the appropriate amount of a fluorocarbon compound in a gaseous dielectric for the present invention, the present inventors carried out an

experiment using 4 different mixtures of SF_6 and C_2F_5CN: (1) SF_6: 99.5 mole %, C_2F_5CN: 0.5 mole %; (2) SF_6: 80 mole %, C_2F_5CN: 20 mole %; (3) SF_6: 50 mole %, C_2F_5CN: 50 mole %; and (4) SF_6: 0 mole %, C_2F_5CN: 100 mole %. Each gas mixture was sealed in a 2-liter container at atmospheric pressure. Inside each container, arcing was produced using copper-tungsten electrodes with a separation of 2mm at a voltage of 30kv. The amount of carbon powder formed during the arcing was measured and the results are shown in Figure 4. When the mole % of C_2F_5CN reached approximately 40%, the slope of the curve abruptly increased, and at mole percentages above this, the amount of carbon powder formed became large. Accordingly, in order to suppress the amount of carbon powder formed during arcing, the amount of a saturated fluorocarbon compound used in the present invention should be no greater than approximately 40 mole %.

A similar arcing experiment was carried out using the electrodes illustrated in Figure 6. A rod-shaped electrode 7 having a hemispherical end and a diameter of 30mm was disposed perpendicularly with respect to a plate electrode 8 having a length of 80mm. In sealed containers containing various combinations of SF_6 and C_2F_5CN at 20°C and atmospheric pressure, a 60 Hz AC voltage was applied between the electrodes and the AC breakdown voltages of the gas mixtures were measured using various gap lengths between the electrodes 7 and 8. The results are shown in

Figure 5. As can be seen from the figure, even when the mole % of C_2F_5CN is extremely low, a significant increase in breakdown voltage over SF_6 alone can be achieved merely by increasing the separation between the electrodes. Accordingly, the lower limit for a saturated fluorocarbon compound is approximately 0.5 mole%.

In addition, an experiment was carried out in which arcing was produced in gaseous mixtures comprising either 100 mole % of C_2F_5CN or 25 mole % C_2F_5CN and 75 mole % SF_6. The gas mixtures were separately sealed in a 2-liter container at 20°C and atmospheric pressure. Arcing was produced inside the container between copper-tungsten electrodes with an electrode separation of 2mm using voltages ranging from 10kv to 30kv. The arc current, the length of time for which the arc was sustained, and the amount of carbon powder formed were measured. The results are plotted in Figure 7, in which the abscissa is the arc current and the ordinate is the weight of carbon powder formed during arcing divided by the length of time for which the arc was sustained. From this experiment, it was learned that the amount of carbon powder formed by the mixture of 25 mole % C_2F_5CN and 75 mole % SF_6 was less than 1/10 the amount formed by C_2F_5CN alone.

Although the above experiments were carried out using mixtures of C_2F_5CN and SF_6, similar results can be expected if another saturated fluorocarbon such as $CBrCl_2$ gas or $c\text{-}C_4F_8$ gas is used instead of

C_2F_5CN. Both of these gases have a high dielectric strength relative to SF_6, as shown in the following table, which gives the relative dielectric strengths compared to the dielectric strength of SF_6 for C_2F_5CN alone, $CBrClF_2$ alone, c-C_4F_8 alone, and mixtures of each of these three gases with SF_6. In the table, all quantities are given as mole percentages.

	GAS COMPOSITION					
	100 % C_2F_5CN	100 % $CBrC_{12}F_2$	100 % c-C_4F_8	25% C_2F_5CN 75% SF_6	25% $CBrC_{12}F_2$ 75% SF_6	25% c-C_4F_8 75% SF_6
DIELECTRIC STRENGTH RELATIVE TO 100% SF_6	1.8	1.4	1.4	1.4	1.15	1.16

Since an electrical apparatus according to the present invention employs a gas mixture which has a higher dielectric strength than SF_6 and which greatly suppresses carbon formation at the time of arcing, for a given rating, an apparatus of smaller size than an apparatus using SF_6 alone as a gaseous dielectric is achievable. Alternatively, an electrical apparatus according to the present invention can have a higher rating than an apparatus of the same physical size which uses SF_6 alone as a gaseous dielectric.

Patent Claims

1. An improved electrical apparatus of the type comprising a sealed chamber, a gaseous dielectric which fills said chamber, a conductor disposed inside said chamber, and a solid insulating member disposed so as to support said conductor, characterized in that said gaseous dielectric comprises a mixture of approximately 60 - 99.5 mole % of SF_6 and approximately 0.5 - 40 mole % of a saturated fluorocarbon compound.

2. An improved electrical apparatus as claimed in Claim 1, wherein said fluorocarbon compound is C_2F_5CN.

3. An improved electrical apparatus as claimed in Claim 1, wherein said fluorocarbon compound is $CBrClF_2$.

4. An improved electrical apparatus as claimed in Claim 1, wherein said fluorocarbon compound is $c\text{-}C_4F_8$.

5. The use of a mixture of approximately 60 to 99.5 mole % of SF_6 and approximately 0.5 to 40 mole % of a saturated gaseous fluorocarbon compound as dielectric medium in electrical apparatuses.

FIG. 1

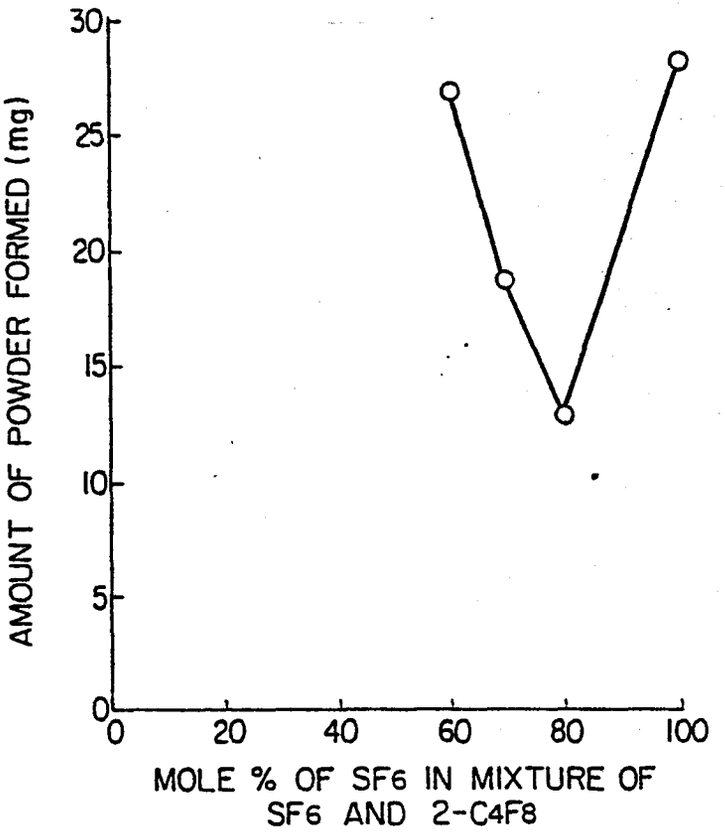

AMOUNT OF POWDER FORMED (mg)
30
25
20
15
10
5
0
0
20
40
60
80
100
MOLE % OF SF6 IN MIXTURE OF
SF6 AND 2-C4F8

FIG. 2

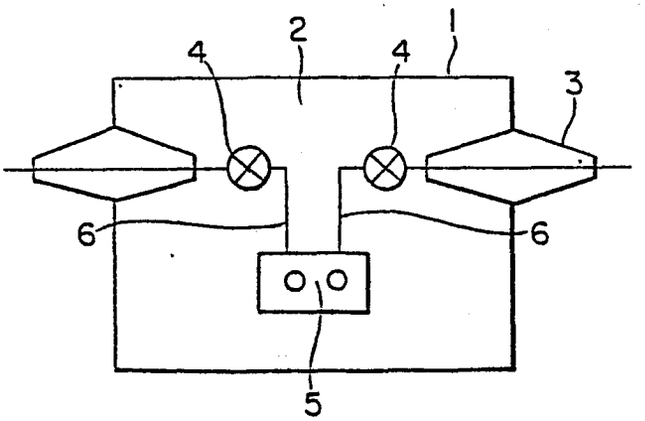

1
2
3
4
4
5
6
6

FIG. 3

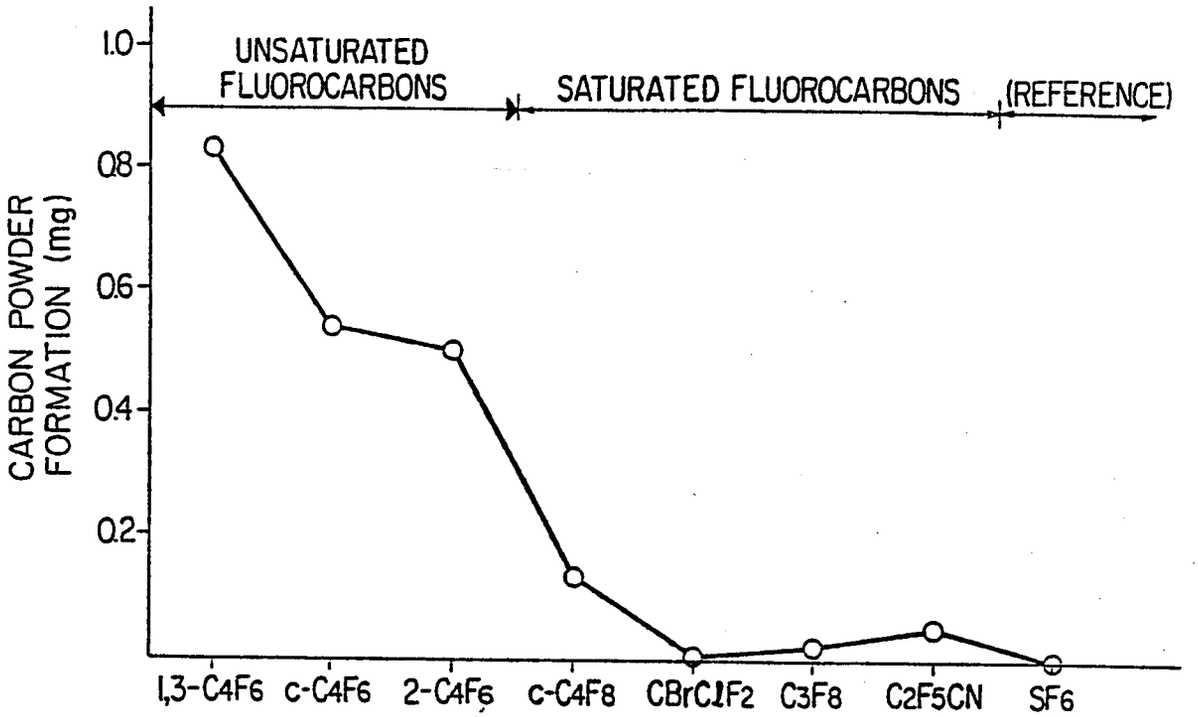

1.0
0.8
0.6
0.4
0.2
CARBON POWDER FORMATION (mg)
UNSATURATED FLUOROCARBONS
SATURATED FLUOROCARBONS
(REFERENCE)
1,3-C4F6
c-C4F6
2-C4F6
c-C4F8
CBrClF2
C3F8
C2F5CN
SF6

FIG. 4

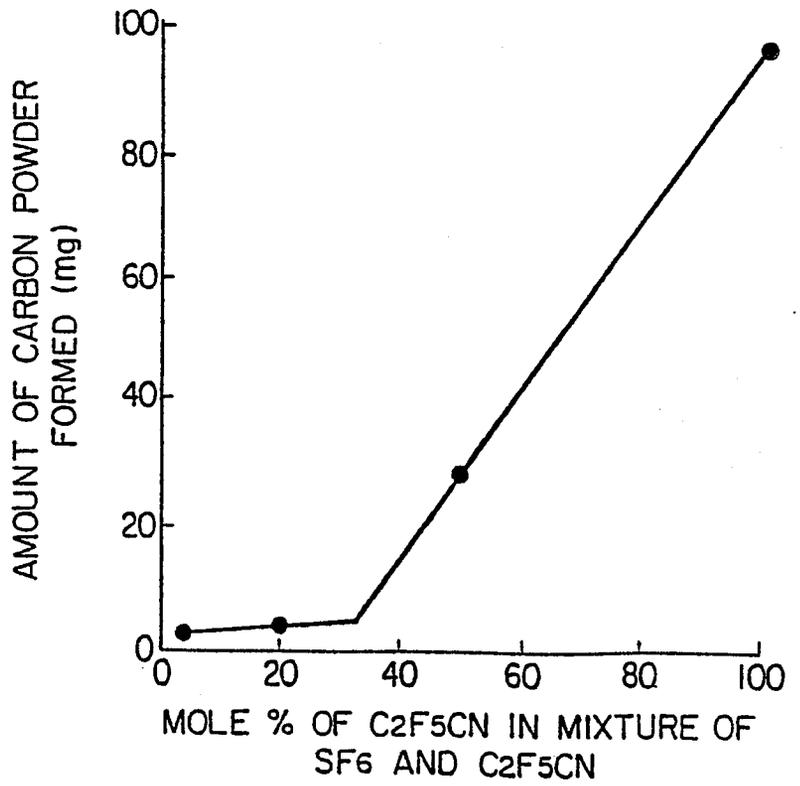

100
80
60
40
20
0
AMOUNT OF CARBON POWDER FORMED (mg)
0
20
40
60
80
100
MOLE % OF C2F5CN IN MIXTURE OF SF6 AND C2F5CN

FIG. 5

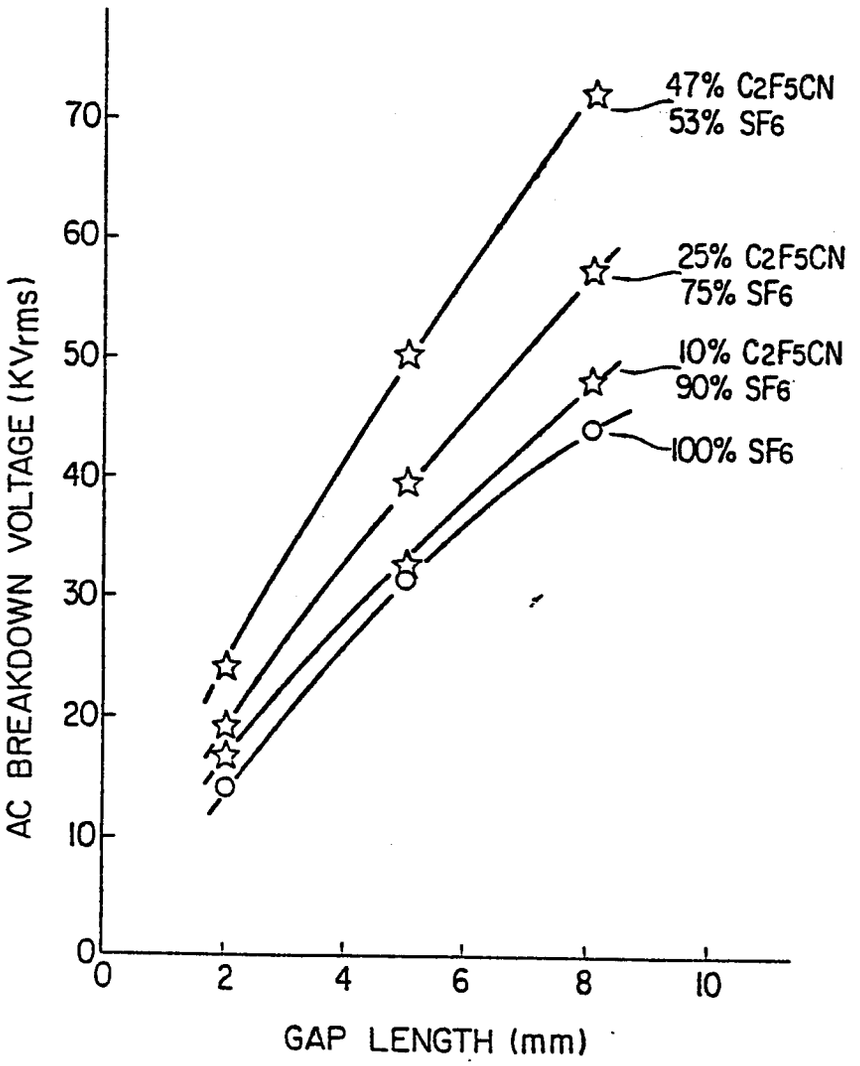

AC BREAKDOWN VOLTAGE (KVrms)
GAP LENGTH (mm)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
47% C2F5CN
53% SF6
25% C2F5CN
75% SF6
10% C2F5CN
90% SF6
100% SF6

FIG. 6

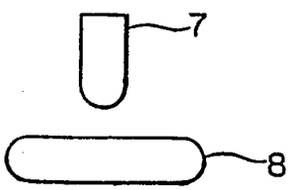
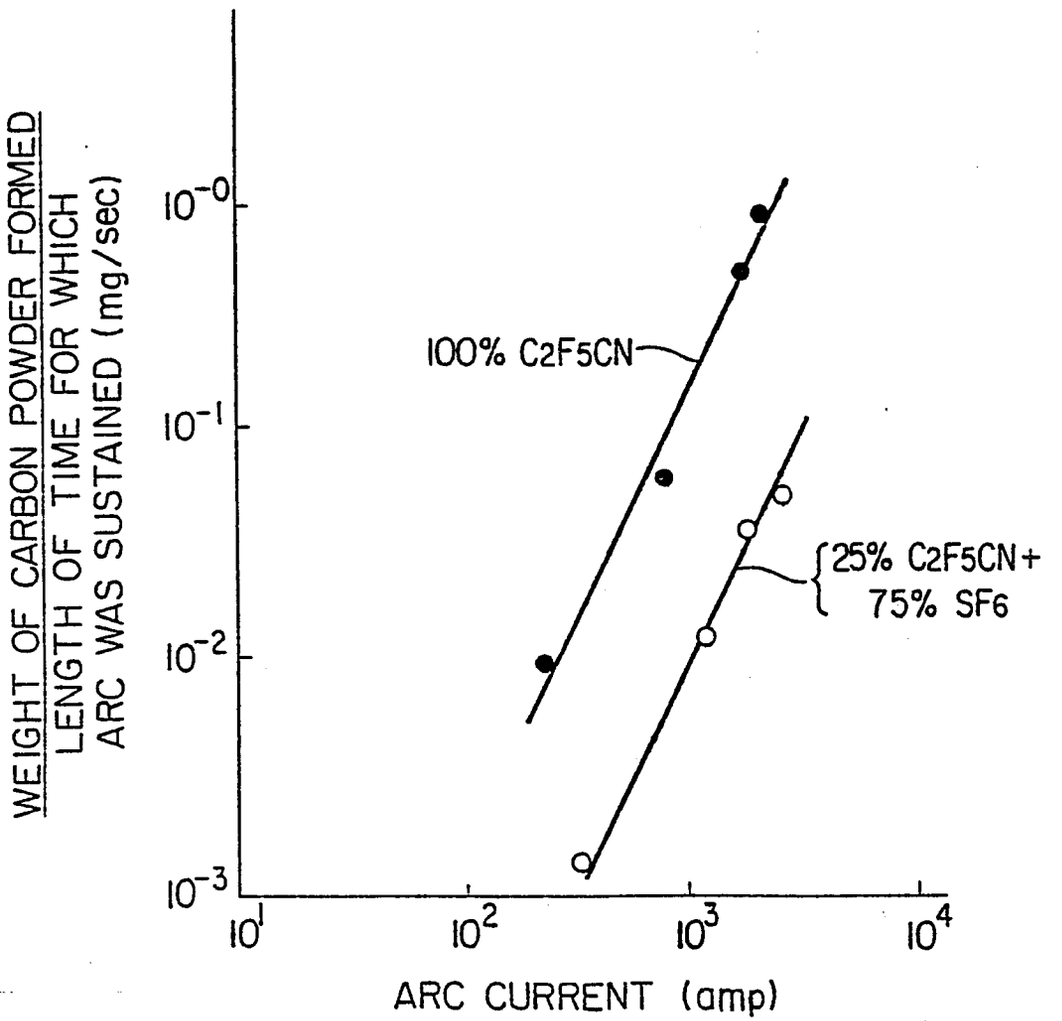

7
8

FIG. 7


WEIGHT OF CARBON POWDER FORMED
LENGTH OF TIME FOR WHICH
ARC WAS SUSTAINED (mg/sec)
10^{-0}
10^{-1}
10^{-2}
10^{-3}
100% C2F5CN
25% C2F5CN+
75% SF6
10^{1}
10^{2}
10^{3}
10^{4}
ARC CURRENT (amp)

European Patent Office

EUROPEAN SEARCH REPORT

0131922
Application number

DOCUMENTS CONSIDERED TO BE RELEVANT

EP 84108219.1

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ³)
	US - A - 4 071 461 (MEARS et al.)		H 01 B 3/56 H 01 H 33/22
X	* Abstract; example 12 *	1,4,5	
Y	* Abstract; examples 4-7, 10-12 *	2,3	
	--		
Y	IEEE TRANSACTIONS ON ELECTRICAL INSULATION, vol. EI-15, nr. 2, April 1980, Piscataway (NJ, USA) J.C. DEVINS "Replacement Gases for SF_6" pages 81-86 * Page 82, fig. 1; page 85, table 1, lines 3,8,9,12,13,16, 17,24,30 *	2,3	
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X	US - A - 4 162 227 (COOKE) * Fig. 3 *	1,5	TECHNICAL FIELDS SEARCHED (Int. Cl. ³)
	----		H 01 B H 01 H H 01 F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	30-08-1984	KUTZELNIGG

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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