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(54) Title: PUMPS FOR HOT AND CORROSIVE FLUIDS

(57) Abstract: A pump for pumping molten metal or molten salt, said pump comprising at least one component manufactured of a substrate and coated with one or more wear and erosion resistant surface layers,wherein said substrate is provided with at least one intermediate binding layer and one outer layer, and said outer layer comprises at least one refractory oxide.

Pumps for hot and corrosive fluids

TECHNICAL FIELD

[001] The present disclosure relates to mechanical pumps for pumping hot, corrosive and erosive fluids like liquid metals and molten salts. The pumps can be of any construction or mechanism of operation, such as radial/centrifugal or axial, wherein at least one component is in contact with the liquid metal or molten salt.

BACKGROUND

[002] The effective service life time of conventional mechanical pumps for liquid metals, normally made of iron base alloys, is typically only a few months or perhaps somewhat longer for molten salt pumps, depending on type of metal or salt and operating temperature.

[003] Ceramic pumps or ceramic impellers that may have excellent corrosion and erosion resistance are known in the art, for example through US 3,776,660 and US 6,019,576. Suggested ceramic materials include graphite and silicon carbide, as disclosed for example in US 5,586,863. However, ceramic materials are mechanically sensitive and break easily when subjected to stress. For instance the fracture toughness of ceramic materials including graphite is generally considered to be too low for use as pump components.

[004] Electro magnetic pump technologies have received a lot of interest in the nuclear industry. A NASA technical report, Liquid-Metal Pump Technologies for Nuclear Surface Power (NASA/TM-2007-214851) gives a review thereof. However, the use of electro-magnetic pumps for liquid metals is disadvantageous due to their poor efficiency.

[005] Pumps for liquid metals and molten salts are used in metallurgical industry, metal coating industry and in chemical industry as well. Additionally there is a growing market for new energy production techniques using liquid metal or molten salts as an energy carrier and/or coolant, such as in liquid metal nuclear reactors,

concentrated solar power plants (CSP) and in fusion reactors. Additionally, molten salts are also used for storage of thermal energy.

[006] The pumps have shown to be a critical component in such nuclear or solar power plants since the overall energy efficiency is dependent on the maximum allowed fluid temperature and flow rate. Today, the maximum operating temperature and choice of fluid is basically limited by corrosion and erosion problems of the pump components. Temperatures of the liquid metals and molten salts used for energy production are typically in the range 200-500 °C but it is desirable to go higher in the future, possibly up to 800 °C.

SUMMARY

[007] One object of the present disclosure is to provide a pump for hot and corrosive fluids wherein the pump has an extended service life.

[008] A particular object is to provide a pump for molten lead or lead bismuth eutectic (LBE) for use in nuclear reactors.

[009] This and other objects are achieved by the aspects and embodiments defined in the independent claims. Further advantageous embodiments have been specified in the dependent claims.

[010] A first aspect is a pump for pumping molten metal or molten salt, said pump comprising at least one component manufactured of a substrate and coated with one or more wear and erosion resistant surface layers, wherein said substrate is provided with at least one intermediate binding layer and one outer layer, and said outer layer comprises at least one refractory oxide.

[011] According to an embodiment of said first aspect, the thickness of the surface coating is 0.2 µm to 1000 µm. Preferably the thickness of the surface coating is 5 - 600 µm.

[012] According to a further embodiment, freely combinable with the above aspect and embodiments, the intermediate binding layer comprises at least one layer of TiN, preferably having a thickness of 0.1 - 5 µm.

[013] According to an embodiment, the substrate is a cemented carbide and the refractory oxide outer layer comprises at least 90 % Al_2O_3. Preferably the outer layer comprises at least 99 % Al_2O_3.

[014] According to yet another embodiment, freely combinable with the above, the cemented carbide comprises at least 80 % WC and a metallic binder, said metallic binder comprising at least one metal selected from the group of Co, Ni, Fe, Cr, Al, Mn, Mo, V, Ti, Ta, Zr and Nb.

[015] According to yet another embodiment, freely combinable with the above, said metallic binder comprises Co and/or Fe and/or Ni and/or Cr and/or Mo in combination with Al. Preferably the binder is a Fe-Al, Ni-Al or a Ni-Cr-Mo-Al binder.

[016] A second aspect relates to a pump for pumping molten metal or molten salt, said pump comprising at least one component manufactured of a substrate and coated with one or more wear and erosion resistant surface layers, wherein said substrate is provided with at least one intermediate binding layer and one outer layer, and said outer layer comprises at least one refractory oxide, wherein the substrate is a nickel based alloy comprising at least 30 wt. % Ni, the outer layer comprises a refractory oxide based on ZrO2, preferably yttria-stabilized zirconia (YSZ), and the intermediate metallic binding layer comprises at least of one metal selected from the group Fe, Ni, Co, Cr or Al.

[017] According to an embodiment of said second aspect, the thickness of the surface coating is 0.2 µm to 1000 µm. The thickness of the surface coating is preferably 5 - 600 µm.

[018] Further aspects and embodiments thereof will become apparent to a skilled person upon study of the detailed description and the comparative example.

DETAILED DESCRIPTION

[019] Before the present invention is described, it is to be understood that the terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting, since the scope of the invention will be limited only by the appended claims and equivalents thereof.

[020] It must be noted that, as used in this specification and appended claims, the singular forms “a”, “an” and “the” also include plural referents unless the context clearly dictates otherwise.

[021] The present disclosure offers a solution to the shortcomings associated with mechanical pumps, mainly erosion and corrosion problems, when using high temperature fluids as energy carrier, energy storage and coolants for future energy production techniques as well as extending the service life time of pumps for the metallurgical industry etc.

[022] By using a metallic substrate, a cermet or a cemented carbide substrate with a metallic binder phase which has good mechanical properties in combination with corrosion and erosion resistant coatings, which are sufficiently well matched regarding thermal expansion, thus enabling good coating adherence, it is possible to construct a mechanical pump for hot fluids with excellent service life time.

[023] The outer surface layer must be hard enough to possess good erosion resistance. Among oxides, the better quality of alumina has 9 out of 10 on the Mohs hardness scale of abrasives and zirconia has a hardness of 8. Alumina and zirconia exhibit good corrosion resistance in for instance liquid lead and LBE. In general, these oxides are suitable for use when pumping a variety of different liquid metals and molten salts of technical interest.

[024] In the same manner alumina has been shown to be highly corrosion resistant in sulphate, nitrate and carbonate molten salts of interest, as an example, for use in concentrated solar power (CSP) applications. Examples of technically interesting salts include, but are not limited to, sodium and potassium nitrates (Na, K)NO3 and lithium, sodium and potassium carbonates (Li,Na,K)CO3.

[025] Several carbides and nitrides such as WC, TiC, B_4C, SiC, TaC, ZrC, TiN, ZrN, BN and carbo-nitrides such as TiCN and TiAlN have a Mohs hardness of 8.5-9.8 and exhibit good erosion resistance and possess sufficiently good high temperature oxidation and corrosion resistance in most of the liquid metals and molten salts of interest for the different industrial applications. For instance, TiC and ZrC have been tested in liquid Pb, Na and Li around 800°C and showed good resistance. However, the adherence of such layers is generally not sufficient for pump components exposed to fluids with high flow rates. For more demanding pump applications, such

as in nuclear reactors, it is necessary to provide an additional outer oxide coating, preferably based on alumina or zirconia.

[026] In the same manner alumina has been shown to be most resistant in molten salts such as potassium and sodium nitrates used for example in concentrated solar power systems (CSP).

[027] In order to achieve perfect growth of an outer protective alumina scale by chemical vapour deposition (CVD) or physical vapour deposition (PVD) it is required to first provide an intermediate layer of a nitride or carbide to promote the ideal oxide structure, TiN, TiC, ZrC, TiCN or mixtures thereof, however preferably TiN. The substrate metal should have a thermal expansion coefficient that is sufficiently close to the coating or coatings, i.e. in the case of alumina as an outer coating, the substrate could preferably be cemented carbide with a metallic binder.

[028] Yttria-stabilized zirconia (YSZ), could for example be used on iron and nickel base alloy substrates since these have more similar thermal expansion coefficients. Suitable techniques to apply YSZ or Thermal Barrier Coatings (TBC) on a metal substrate are Electron Beam Physical Vapor Deposition (EBPVD), Air Plasma Spray (APS), High Velocity Oxygen Fuel (HVOF), Electrostatic Spray Assisted Vapour Deposition (ESAVD) or Direct Vapor Deposition.

[029] YSZ can also be applied directly on a metal substrate but the use of a metallic and/or oxide binding layer (bond coat) as an intermediate layer should be applied before the outer YSZ-layer is deposited. Such a metallic bond coat, Fe- or Ni-based, should preferably contain chromium and some per cent aluminium in order to form a thin alumina scale for optimal adhesion of the outer YSZ-layer.

[030] A pump for hot and corrosive fluids according to aspects and embodiments of the present disclosure comprises at least one component coated with one or more wear and erosion resistant surface layers. This component can be an impeller vane, an impeller or a part of or the entire inner surface of the pump housing. The impeller is he most important part since it is subjected to high flow rates.

[031] The substrate material may be selected from the following group of materials: steels, stainless steels, nickel-, cobalt-, molybdenum-, tantalum- and tungsten-based alloys, cermets and cemented carbides. A material of particular

interest is tungsten carbide, which can be without a binder, or include a metallic binder.

[032] The binder can comprise at least on metal selected from the group of Co, Ni, Fe, Cr, Al, Mn, Mo V, Ti, Ta, Zr and Nb. According to a preferred embodiment the binder is chosen with respect to its stability in liquid lead and LBE at high temperatures and at low oxygen potentials.

[033] The surface coating comprises at least one layer of oxides, nitrides and carbides or mixtures thereof, preferably the coating comprises at least two layers wherein the carbides and/or nitrides comprises at least one element selected from Zr, Ti, Ta, V, Hf, Nb, W, B, Mo, Cr, Al, and Si and/or the oxides comprises aluminium oxide and zirconium oxide and stabilized or doped oxides thereof.

[034] The total thickness of the surface coating is 0.2 μm to 1000 μm depending on the selected coating materials and application techniques. CVD coatings typically have a thickness of about 1 to about 20 μm and APS coatings typically have a thickness of about 50 to about 600 μm.

[035] In a preferred embodiment, the pump comprises an impeller or at least one impeller vane made of a nickel-based alloy provided with a coating comprising one outer layer of yttria stabilized zirconia (YSZ).

[036] Another preferred embodiment comprises of an impeller or at least one impeller vane wherein the substrate is a cemented carbide and the coating comprises at least one intermediate layer, preferably TiN, and, optionally, at least one layer of Al_2O_3. Preferably, the cemented carbide comprises at least 80 % WC and a metallic binder, the metallic binder comprising at least on metal selected from the group of Co, Ni, Fe, Cr, Al, Mn, Mo, V, Ti, Ta, Zr and Nb. The binder is chosen from Fe, Ni, Cr, Mo and Al, preferably the binder contains an amount of Al such that it easily can form aluminium oxide if the surface coating should be damaged.

[037] A particular use of the coated cemented carbide is the use as a structural material for at least one pump component in a pump for pumping liquid lead or LBE, in particular in a nuclear reactor, wherein the liquid lead or LBE has an oxygen concentration below the lead oxide formation limit.

[038] Another use is the pumping of molten salts, such as carbonate, nitrate and sulphate salts for use in energy applications such as CSP.

[039] A nickel-based alloy comprising an outer layer of yttria-stabilized zirconia (YSZ) is also a suitable material for the above uses.

EXAMPLE 1

[040] In the present example a laboratory-screening test of seven different materials were conducted in flowing lead, which simulates the erosive and corrosive environment a pump component would be exposed to in a liquid heavy metal. The materials and material combinations that were tested are presented in Table 1 below.

Table 1. Material samples subjected to comparative erosion and corrosion test

No.	Description
1	Uncoated carbon steel
2	Uncoated austenitic stainless steel
3	Uncoated Kanthal APMT FeCrAl alloy
4	Pre-oxidized Kanthal APMT FeCrAl alloy, i.e. with a thin *in–situ* formed alumina scale
5	Commercial cemented carbide TiN coated tungsten carbide (WC + 6% Co)
6	Commercial Al_2O_3 (ceramic)
7	Commercial thermal barrier coating (TBC) coated nickel-based alloy. Substrate, Haynes 230, air plasma spray (APS) coated with 360 µm yttria stabilized zirconia (YSZ) (ZrO_2 with 7% Y_2O_3) as a topcoat and 150 µm intermediate binder coating comprising of Ni-Co-Cr-Al-Y.

[041] An erosion test facility was constructed by the inventors. In the erosion test facility, housing up to 10 kg of lead, a theoretical flow rate up to 10 m/s could be achieved by rotating the liquid metal using a rotating disk with a diameter of 15 cm. The disk, immersed into the liquid metal, was rotated using an electric motor coupled to the disk using a stainless steel shaft. Air ingress was reduced to a minimum using standard vacuum copper sealing, and the amount of dissolved oxygen in the liquid lead was controlled by means of an Ar-H2-H2O gas mixture. The test samples were placed close to the periphery of the rotating disk, where the highest flow rates were expected. The facility was heated using a 1000 W band heater mounted on the outside of facility and the temperature was controlled using thermocouples of type K and a PID regulator. The test conditions are shown in Table 2.

Table 2. Test conditions	
Amount of lead	10 kg (approximately 1 dm^3)
Flow rate (theoretical)	7 m/s
Temperature	550°C
Oxygen concentration	10^{-7} weight-%
Exposure time	300 h

[042] The samples were removed after 300 h and post-exposure examination was carried out using a standard optical microscope reaching magnifications up to about 1000x. The tested materials were evaluated with respect to before and after appearance, color and erosion cavitation, as well as from the amount of lead attached to the sample, i.e. wettability.

[043] The screening test revealed large differences in erosion and corrosion resistance between the tested specimens. The uncoated steel samples 1 – 3 showed severe erosion and corrosion damage, meaning a noticeable shift in appearance from smooth metallic surfaces to dark uneven and notched surfaces. The least

damage was found on the uncoated FeCrAl alloy, sample 3. The coated samples, including the pre-oxidized FeCrAl alloy, sample 4, showed no or little damage.

[044] Sample 6, the commercial Al_2O_3-ceramic and sample 7, the YSZ coated Ni-base ally, were virtually unaffected. The commercial cemented carbide sample, coated with TiN, showed a significantly better erosion resistance than the uncoated steels in the test.

[045] The screening test thus confirmed that structural components of a pump for liquid lead could be effectively protected from the bulk metal by stable coatings. Particular useful coatings comprise Al_2O_3 and ZrO_2.

[046] The screening test thus confirmed that structural components of a pump for liquid lead could be effectively protected from the bulk metal by stable coatings. Particular useful coatings comprise Al_2O_3 and ZrO_2. Pumps with such coatings or including components with such coatings are well suited for use in different systems for the generation of energy, such as but not limited to concentrated solar power and nuclear energy. They are particularly well suited for use in lead or LBE cooled reactors in the nuclear industry.

[047] The invention has mainly been described above with reference to a few embodiments. However, as is readily appreciated by a person skilled in the art, other embodiments than the ones disclosed above are equally possible within the scope of the invention, as defined by the appended patent claims.

- - -

CLAIMS

1. A pump for pumping molten metal or molten salt, said pump comprising at least one component manufactured of a substrate and coated with one or more wear and erosion resistant surface layers,

wherein said substrate is provided with at least one intermediate binding layer and one outer layer, and said outer layer comprises at least one refractory oxide.

2. The pump according to claim 1, wherein the thickness of the surface coating is 0.2 µm to 1000 µm.

3. The pump according to claim 1, wherein the thickness of the surface coating is 5 – 600 µm.

4. The pump according to any one of the preceding claims, wherein the intermediate binding layer comprises at least one layer of TiN, preferably having a thickness of 0.1 – 5 µm.

5. The pump according to any one of the preceding claims, wherein the substrate is a cemented carbide and the refractory oxide outer layer comprises at least 90 % Al_2O_3.

6. The pump according to claim 5, wherein the outer layer comprises at least 99 % Al_2O_3.

7. The pump according to claim 5, wherein the cemented carbide comprises at least 80 % WC and a metallic binder, said metallic binder comprising at least one metal selected from the group of Co, Ni, Fe, Cr, Al, Mn, Mo, V, Ti, Ta, Zr and Nb.

8. The pump according to claim 7, wherein said metallic binder comprises Co and/or Fe and/or Ni and/or Cr and/or Mo in combination with Al.

9. The pump according to claim 8, wherein the binder is a Fe-Al, Ni-Al or a Ni-Cr-Mo-Al binder.

10. The pump according to any one claims 1 - 3, wherein
the substrate is a nickel based alloy comprising at least 30 wt. % Ni,
the outer layer comprises a refractory oxide based on ZrO_2, preferably yttria stabilized zirconia (YSZ), and

the intermediate metallic binding layer comprises at least of one metal selected from the group Fe, Ni, Co, Cr or Al.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2017/050431

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: C23C, F04C, F04D, G21C, G21D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE, DK, FI, NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, PAJ, WPI data, COMPENDEX, INSPEC, MEDLINE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	RIVAI, A.K. et al, "Compatibility of surface-coated steels, refractory metals and ceramics to high temperature lead-bismuth eutectic", Progress in Nuclear Energy, available 2008-01-03, 2008, volume 50, No 2-6, pages 560-566; abstract; page 560, column 2 - page 560, column 2; page 561, column 1, paragraph [0003] - page 561, column 1, paragraph [0003]; page 561, column 2, paragraph [0003] - paragraph [0003]; page 565, column 2, paragraph [0003] - page 565, column 2, paragraph [0003]	1-4
A		5-9
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31-08-2017	01-09-2017

Name and mailing address of the ISA/SE	Authorized officer
Patent- och registreringsverket Box 5055 S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Anna-Maj Magnusson Telephone No. + 46 8 782 28 00

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KURATA, Y. et al, Corrosion behavior of Al-surface-treated steels in liquid Pb-Bi in a pot, Y. Kurata, Journal of Nuclear Materials, Volume 335, Issue 3, 1 December 2004, pages 501-507; abstract; figure 1	1-4
A		5-9
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A	GLASBRENNER et al, Exposure of pre-stressed T91 coated with TiN, CrN and DLC to Pb-55.5Bi, Journal of Nuclear Materials, Volume 356, Issues 1-3, 15 September 2006, pages 213-221; abstract --	1-9
A	ZHANG; J, A review of steel corrosion by liquid lead and lead-bismuth, Corrosion Science, Volume 51, Issue 6, June 2009, pages 1207-1227; abstract --	1-9
A	EJENSTAM, J. et al, Oxidation studies of Fe10CrAl-RE alloys exposed to Pb at 550 °C for 10,000 h, Journal of Nuclear Materials, Volume 443, Issues 1-3, November 2013, pages 161-170; abstract --	1-9
A	DAIA, Y. et al, FeCrAlY and TiN coatings on T91 steel after irradiation with 72 MeV protons in flowing LBE, Journal of Nuclear Materials, Volume 431, Issues 1-3, December 2012, pages 66-76; abstract --	1-9
A	GARCIA, F. et al., Advanced Al2O3 coatings for high temperature operation of steels in heavy liquid metals: a preliminary study, Corrosion Science, Volume 77, December 2013, pages 375-378; abstract --	1-9
A	EP 0150515 A1 (NERATOOM), 7 August 1985 (1985-08-07); abstract --	1-9
A	JP 2001153063 A (KOHAN KOGYO ET AL), 5 June 2001 (2001-06-05); (abstract) Retrieved from: WPI database -- --------	1-9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2017/050431

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

The following separate inventions were identified:

1: Claims 1-9 directed to a pump for pumping molten metal, said pump comprising at least one component manufactured of a substrate and coated with an intermediate layer and an outer layer. The substrate consists of cemented carbide, at least 80 % WC, the intermediate binding layer consists of TiN and the outer layer of Al_2O_3.

.../...

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.: 1-9

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Continuation of: Box No. III

2: Claims 1-3 and 10 directed to a pump for pumping molten metal, said pump comprising at least one component manufactured of a substrate and coated with an intermediate layer and an outer layer. The substrate consists of a nickel based alloy and the intermediate binding layer comprises at least one metal selected from the group Fe, Ni, Co, Cr or Al, and the outer layer is based on ZrO_2, preferably yttria stabilized zirconia (YSZ).

A partial search has been carried out, which relates to invention 1 above.

The present application has been considered to contain 2 inventions which are not linked in such a way that they form a single general inventive concept, as required by Rule 13 PCT for the following reasons:

The single general concept of the present application is to provide a pump with an extended service life for hot and corrosive metal and salt melts. This object is achieved by manufacturing parts of the pump in a certain material and coating it with certain layers.

Document D1 demonstrates that it is known to coat materials used in metal melts with layers of for example Al_2O_3. Consequently, the single general concept lacks inventive step relative to document D1.

Thus, the single general concept is obvious and cannot be considered as a single general inventive concept in the sense of Rule 13.1 PCT.

No other features can be distinguished which can be considered as the same or corresponding special technical features in the sense of Rule 13.2 PCT.

Thus, the application lacks unity of invention.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SE2017/050431

EP	0150515	A1	07/08/1985	NONE
JP	2001153063	A	05/06/2001	NONE

Continuation of: second sheet

International Patent Classification (IPC)

C23C 4/10 (2016.01)
C23C 14/06 (2006.01)
C23C 14/08 (2006.01)
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F04D 7/06 (2006.01)
F04D 29/02 (2006.01)
G21C 15/247 (2006.01)
G21D 1/04 (2006.01)