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(54) Title: SEGMENTED CORE TRANSFORMER

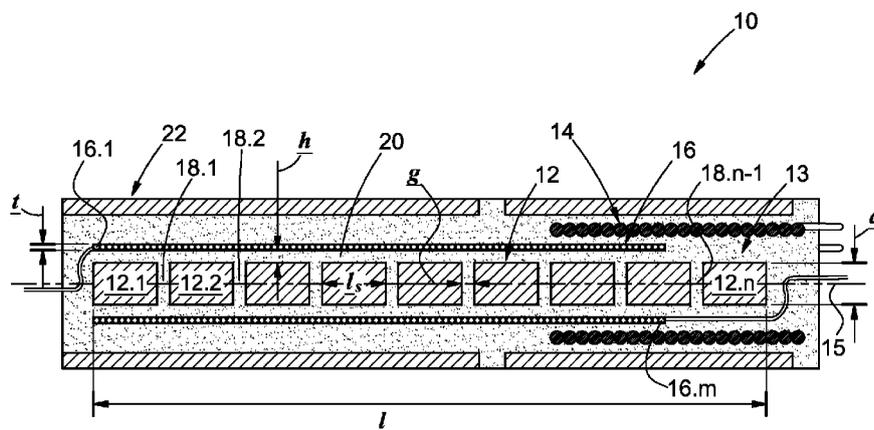


FIGURE 1

(57) Abstract: The transformer (10) comprises a core (12), a primary winding (14) and a secondary winding 16. The core comprises an elongate limb (13) having a main axis (15) and comprising a plurality of segments (12.1 to 12. n) of a magnetic material and gaps (18.1 to 18.n-1) between segments arranged in alternating relationship along the main axis (15). The main axis (15) is parallel to a direction of a magnetic field in the limb (13). Each gap has a linear segment separating extent (g) which is parallel to the main axis (15). The value of n is larger than three and the gaps are filled with an isolation medium (20).



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SEGMENTED CORE TRANSFORMER

INTRODUCTION AND BACKGROUND

This invention relates to transformers, a core for a transformer and an
5 ignition system for a vehicle comprising a transformer.

A known vehicle ignition system transformer comprises a unitary solid or
laminated core, such as a pencil core, of a magnetic material. Primary and
secondary windings of the transformer are wound around the core. The
10 transformer must comply with a number of requirements. The solid core
must provide good magnetic coupling between the primary and secondary
windings, so that energy can be transferred from the primary winding to
the secondary winding during a single pulse. The primary and secondary
inductances must be large enough so that sufficient energy can be stored
15 in the magnetic core, so that the maximum primary current is not too high
and so that the spark duration is long enough for a stable spark. The large
secondary inductance requires a large number of turns. This results in the
secondary winding having a resistance of several kilo-ohm. The resistance
results in heating of the windings, which must be taken away. Hence, the
20 transformer must provide for sufficient heat transfer from the windings to
the outside of the transformer. The magnetic design must be such as to
prevent core saturation during high voltage generation. Furthermore,
enough magnetic material is required to store sufficient energy in the

magnetic field. Very good electrical isolation is required between the secondary windings and the magnetic core. The maximum secondary voltage is normally larger than 30 kV and the magnetic core is normally conductive. The isolation between the core and windings must be able to withstand the maximum voltage. Sufficient isolation between the windings is also required. Because most magnetic materials meeting these requirements are conductive or have a low dielectric strength, a relatively thick isolation layer is required between the core and the secondary winding, which is undesirable. A transformer suitable for use in an automobile engine must be able to operate at temperature between about -40°C and about +140°C. Due to different thermal expansion coefficients between the core and the isolation material, mechanical stresses develop. After a number of thermal cycles, gaps or cracks between the magnetic material and isolation material may develop, which may be fatal.

To achieve these requirements while also reducing the volume of the transformer becomes very difficult. Because of the large number of turns in a small volume, the capacitance of the winding (including inter-turn capacitance) becomes large, which results in more energy required to generate a certain high voltage.

OBJECT OF THE INVENTION

Accordingly, it is an object of the present invention to provide an alternative transformer, core therefor and ignition system, with which the applicant believes the aforementioned disadvantages may at least be alleviated or which may provide useful alternatives for the known transformers, cores and ignition systems.

SUMMARY OF THE INVENTION

According to the invention there is provided a transformer comprising a core, a primary winding and a secondary winding, the core comprising an elongate limb having a main axis, a plurality (n) of segments of a magnetic material and gaps between segments arranged in alternating relationship along the main axis, each gap having a linear segment separating extent which is parallel to the main axis, n being larger than 3 and the gaps being filled with an isolation medium.

Each segment may comprise a cylindrical body having a main axis and comprising a side wall extending between opposed first and second end walls. The gap between first and second adjacent segments may extend between the second end wall of the first segment and the first end wall of the second segment. The main axes of the segments may be aligned with the main axis of the limb. At least respective centre regions of the first and second end walls of a segment may extend parallel to one another.

Edges between the end walls and the side wall may be rounded. The body may be circular in transverse cross section or generally rectangular. In the latter case corner regions of the side wall may also be rounded.

5 The value of n may be larger than any one of 4, 5, 6, 7, 8, 9 and 10.

The segments may be solid or laminated and arranged linearly.

10 The segments may have the same length and may be equi-spaced, so that the widths of the gaps are equal. In other embodiments, at least some of the segments may have different lengths and at least some of the gaps may have different widths.

15 The primary and secondary windings may be wound concentrically around the core. The secondary winding may be located concentrically closer to the core than the primary winding.

20 The primary and secondary windings may be wound concentrically around the core from one end of the core to the other. Both of these windings may be wound concentrically around a part of the linearly arranged segments. The windings may be wound linearly along the linear arrangement of segments, so that each winding comprises a plurality of linearly arranged

and abutting turns. The primary and secondary windings may overlap with one another or may not overlap.

5 The transformer may comprise an outer jacket of a magnetic material housing the core, the primary winding and the secondary winding.

The outer jacket may comprise a single elongate hollow cylindrical body.

Alternatively, the outer jacket may comprise a plurality of jacket segments.

10 Each jacket segment may be hollow cylindrical in configuration and the jacket segments may be linearly arranged.

The isolation medium may comprise at least one of a liquid and a solid.

15 All voids (between windings, between segments, between windings and segments and between windings and the outer jacket) may be filled with the isolation medium.

20 The invention also includes within its scope a core comprising an elongate limb having a main axis, a plurality (n) of segments of a magnetic material and gaps between segments arranged in alternating relationship along the main axis, each gap having a linear segment separating extent which is

parallel to the main axis, n being larger than 3 and the gaps being filled with an isolation medium.

Yet further included within the scope of the present invention is an ignition system for a vehicle comprising a transformer as herein defined and/or
5 described and wherein one end of the secondary winding is connected to at least one spark plug and wherein the transformer is driven resonantly by an oscillating circuit connected to the primary winding.

10 The oscillating frequency of the oscillating circuit may be between 100kHz and 3MHz.

BRIEF DESCRIPTION OF THE ACCOMPANYING DIAGRAMS

The invention will now further be described, by way of example only, with
15 reference to the accompanying diagrams wherein:

figure 1 is a longitudinal section through a transformer according to the invention; and

figure 2 is a block diagram of relevant parts of an ignition system comprising the transformer.

20

DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

A transformer according to the invention is generally designated by the reference numeral 10 in the figures.

The transformer may find particular application in vehicle ignition systems.

The transformer 10 comprises a core 12, a primary winding 14 and a secondary winding 16. The core comprises an elongate limb 13 having a main axis 15, a plurality (n) of segments (12.1 to 12.n) of a magnetic material and gaps (18.1 to 18.n-1) between segments arranged in alternating relationship along the main axis 15. The main axis 15 is parallel to a direction of a magnetic field in the limb. Each gap has a linear segment separating extent g which is parallel to the main axis. The value of n is larger than three (3) and the gaps are filled with an isolation medium 20.

The isolation medium is required to have a large dielectric strength, preferably higher than 9kV/mm, more preferably higher than 20kV/mm over the temperature range of -40°C to +140°C. There are many plastic materials available that meet this requirement. The isolation material must preferably also have a low relative permittivity ϵ_r , typically lower than 4 and preferably lower than 3.

The magnetic material is required to have a high permeability, high saturation flux density and low loss over a -40°C to +140°C temperature range and DC to 1 MHz frequency range. An example of such a material is the soft ferrite TSC-50ALL having a relative permeability higher than 3000

for flux densities lower than 3000 Gauss, for frequencies up to 1 MHz and temperatures between -30°C and $+200^{\circ}\text{C}$. This ferrite's core loss is less than 10 mW/cm^3 at a frequency of 500 kHz, a flux density of 100 Gauss and a temperature of 70°C .

5

In a preferred embodiment, the segments 12.1 to 12.n are arranged linearly and adjacent segments are separated by the gaps 18.1 to 18.n-1. The primary winding 14 and the secondary winding 16 are wound concentrically around the core. Each winding comprises a plurality of turns. More particularly secondary winding 16 comprises turns 16.1 to 16.m. A concentric outer jacket 22 of a magnetic material provides a magnetic return path. The jacket may comprise a single hollow cylindrical body or may comprise two or more hollow cylindrical segments. The segments may be linearly arranged. The magnetic material of the core segments and the jacket may be the same or may be different materials.

10

15

The core has a length l , each segment has a length l_s and adjacent segments are separated by a gap extending transversely, typically perpendicularly, relative to the main axis 15. Each gap has a linear segment separating extent or dimension g which is parallel to the main axis 15. The diameter of the core is d . The core 12 and secondary winding 16 are spaced a distance h . This space is also filled by the isolation material 20.

20

Assume the dielectric material 20 has a dielectric strength of 9kV/mm with relative permittivity $\epsilon_r=4$, 40 kV between a first turn 16.1 and the last turn 16.m of the secondary winding 16 and that a thickness t of the winding is 0.5mm. A transformer comprising a conventional solid core of length $l =$
5 55mm and diameter $d = 9$ mm is compared hereinafter to a comparable transformer 10 according to the invention and as shown in the figures.

For the conventional solid core transformer (not shown) with a distance h between the core and the secondary winding, a minimum isolation
10 thickness of $h=2.2$ mm is required, assuming that the core is at a voltage of 20kV when there is a 40kV difference between the first and last turn of the secondary winding. The isolation annulus has a volume of 4.3cm^3 . The capacitance between the secondary winding and the core is 0.56pF/mm or 31pF for the whole length l . The capacitance between the first 5mm of
15 turns and the last 5mm of turns is given by the capacitance of the first 5mm of turns and the core in series with the capacitance between the core and the last 5mm of turns, which is 1.4 pF. The inductance was measured to be about 64nH per turn squared when using TSC-50ALL ferrite. The length of wire per turn is about 40mm, giving an inductance of 36pH/mm
20 squared of wire.

For the segmented core 10 according to the invention having ten (10) segments of $l_s = 5$ mm long, there is 4kV between the first and last turns

around a segment, when there is a voltage of 40kV between the first and last turn of the secondary winding. This requires a segment to winding distance h filled by the isolation material 20 of at least 0.44mm. Assume $h=0.5\text{mm}$, the volume of the isolation annulus in this case is then 0.8cm^3 .

5 The nine (9) gaps 18.1 to 18.9 must withstand 40kV, which is 4.4kV per gap, requiring a gap width $g = 0.5 \text{ mm}$ between segments. This corresponds to a volume of 0.3cm^3 between adjacent segments. The capacitance between segments is 4.5pF and between the winding 16 and a segment 2pF/mm. The capacitance between the first 5mm of turns from
10 turn 16.1 and the last 5mm of turns to turn 16.m is 0.45pF. The inductance was measured to be about 27nH per turn squared. The length of wire per turn 16.1 to 16.m is 31mm, giving an inductance of 28pH/mm squared for a certain length of wire.

15 Although the inductance is less for a given number of turns (64nH/mm compared to 27nH/mm), it is presently believed that more energy can be stored in the magnetic material due to the number of gaps. For the same energy requirements, the segmented core 10 therefore would require a shorter length of winding wire, which would have a lower winding
20 resistance than the corresponding winding of a solid core transformer.

Also, the segmented core need 1.1cm^3 compared to 4.3cm^3 isolation material for the solid core. This is significant when compared to the core's

volume of 3.5cm^3 . Hence, it is believed that segmentation of the core 12 would reduce the total isolation requirement over the whole length l of the core 12. Turns 16.1 to 16.m may be wound closer to the core 12. The resulting smaller radius of the turns reduces the winding wire length and resistance. The shorter segments 12.1 to 12.n may give rise to lower thermal-mechanical stresses, and the distributed gaps between segments may provide higher saturation energy. The capacitance of the secondary winding between the first and last 5mm of turns is significantly reduced from 1.4pF to 0.45pF.

10

The transformer may find particular application in an ignition system 30 (shown in figure 2) for a vehicle (not shown). The transformer may be driven resonantly, similarly to a Tesla coil, by an oscillating circuit 32 at an oscillating frequency f_o of about 100kHz - 3MHz, where energy is transferred from the primary winding 14 to the secondary winding 16 during each cycle of several cycles. It is expected that the requirement for good coupling between the primary winding 14 and secondary winding 16 would not be as strict as with a conventional transformer comprising a conventional unitary core.

20

Turn 16.1 is normally connected to a spark plug 34 and turn 16.m may be grounded or connected to an energy (voltage or current) source. The

magnetic core 12 may be designed to saturate when energy is transferred directly through the secondary winding 16 for fast energy transfer.

CLAIMS

1. A transformer comprising a core, a primary winding and a secondary winding, the core comprising an elongate limb having a main axis, a plurality (n) of segments of a magnetic material and gaps between segments arranged in alternating relationship along the main axis, each gap having a linear segment separating extent which is parallel to the main axis, n being larger than 3 and the gaps being filled with an isolation medium.
2. A transformer as claimed in claim 1 wherein n is larger than any one of 4, 5, 6, 7, 8, 9 and 10.
3. A transformer as claimed in any one of the preceding claims wherein the segments are solid, wherein the main axis is linear and wherein the primary and secondary windings are wound concentrically around the core.
4. A transformer as claimed in any one of the preceding claims wherein at least some of the segments are laminated, wherein the main axis is linear and wherein the primary and secondary windings are wound concentrically around the core.

5. A transformer as claimed in claim 3 or claim 4 wherein the secondary winding is located concentrically closer to the core than the primary winding.
- 5 6. A transformer as claimed in any one of the preceding claims comprising an outer jacket of a magnetic material housing the core, the primary winding and the secondary winding.
7. A transformer as claimed in claim 6 wherein the outer jacket
10 comprises a single elongate hollow cylindrical body.
8. A transformer as claimed in claim 6 wherein the outer jacket comprises a plurality of jacket segments.
- 15 9. A transformer as claimed in claim 8 wherein each jacket segment is hollow cylindrical in configuration and wherein the jacket segments are linearly arranged.
- 20 10. A transformer as claimed in any one of the preceding claims wherein the isolation medium comprises at least one of a liquid and a solid.

11. A transformer as claimed in any one of claims 6 to 9 wherein voids within the outer jacket are filled by the isolation medium comprising at least one of a liquid and a solid.
- 5 12. A core for a transformer comprising an elongate limb having a main axis, a plurality (n) of segments of a magnetic material and gaps between segments arranged in alternating relationship along the main axis, each gap having a linear segment separating extent which is parallel to the main axis, n being larger than 3 and the
10 gaps being filled with an isolation medium.
13. An ignition system for a vehicle comprising a transformer as claimed in any one of claims 1 to 11, wherein one end of the secondary winding is connected to at least one spark plug and
15 wherein the transformer is driven resonantly by an oscillating circuit connected to the primary winding.
14. An ignition system as claimed in claim 13 wherein an oscillating
20 frequency of the oscillating circuit is between 100kHz and 3MHz.

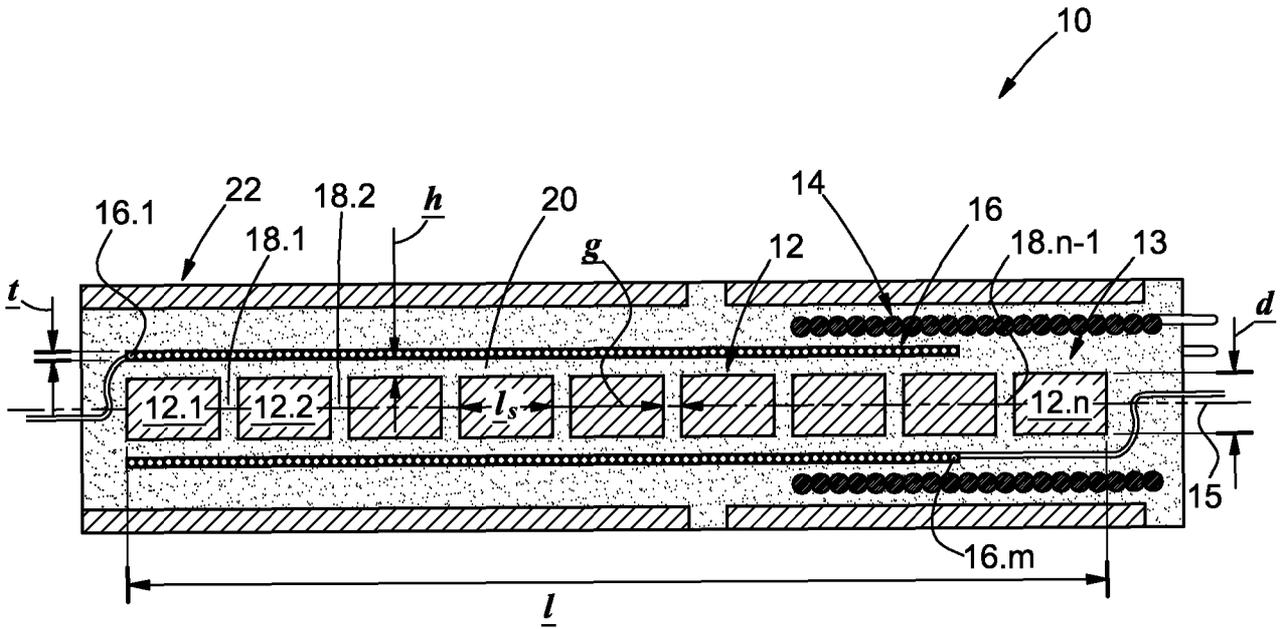


FIGURE 1

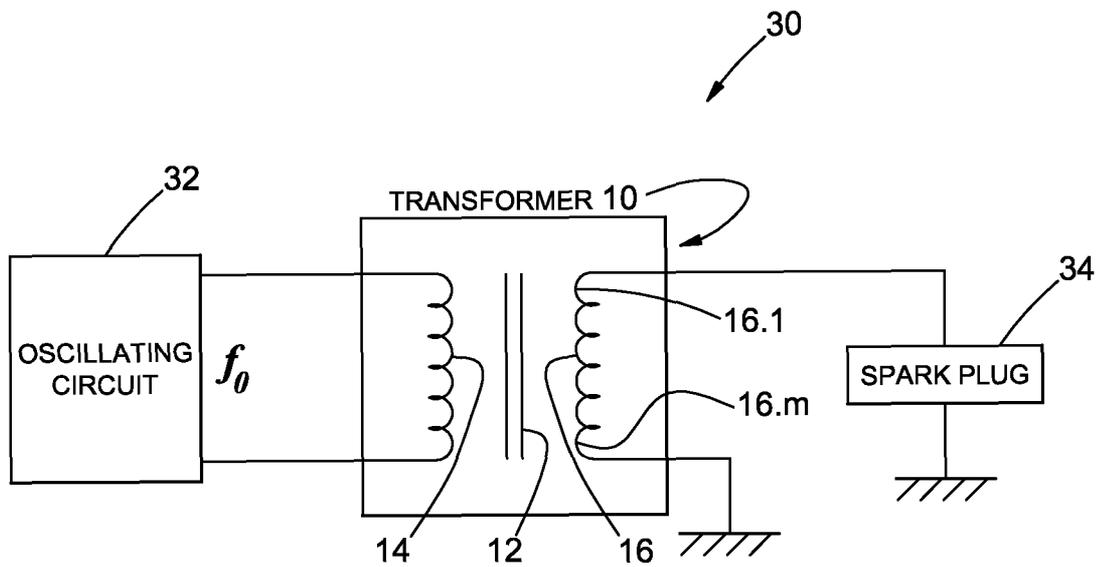


FIGURE 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2010/052679

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01F3/14 H01F27/32 H01F38/12 H01T13/44
ADD.

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)
H01F H01T

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	GB 2 037 089 A (PHILIPS NV) 2 July 1980 (1980-07-02) claims 1,2 figures	1-4,10, 12 13,14
X Y	DE 12 45 487 B (WESTINGHOUSE ELECTRIC CORP) 27 July 1967 (1967-07-27) claim 1 column 3, line 29 - line 54 figures 2,3	1,2,4, 10-12 6-8,11, 13,14
X Y	DE 10 2006 026466 B3 (SIEMENS AG [DE]) 6 December 2007 (2007-12-06) claims paragraph [0018] figure 2	1-4,10, 12 5,13,14
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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 document 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

30 September 2010

Date of mailing of the international search report

06/10/2010

Name and mailing address of the ISA/

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Stichauer, Libor

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2010/052679

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	paragraphs [0007], [0044], [0048], [0051], [0076] figures 1,3,8,12	13,14
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A	claims 1-3,6 column 4, line 23 - line 25 column 6, line 44 - line 45 figures 1,8B,8C,10	1,3,4,9, 12,13
Y	----- WO 2007/135584 A1 (UNIV NORTHWEST [ZA]; VISSER BAREND [ZA]; KRUGER PETRUS PAULUS [ZA]) 29 November 2007 (2007-11-29)	13,14
A	claims 1,2,5,6 page 7, line 19 - page 8, line 4 page 24, line 1 - line 6	1,3-7,12
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A	claims 14,18 paragraph [0149] figures 5,7,17,22,24,26,30,32,34	
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	claims 1-3 paragraphs [0024], [0028], [0035] figure 3	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2010/052679

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:

see additional sheet

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 an 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.:

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.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-14

a conventional magnetic core comprising a plurality of magnetic segments separated by a plurality of gaps filled with an isolation medium (claim 12); a conventional transformer comprising said core (claims 1-11); a resonantly driven ignition system comprising said transformer (claims 13-14)

1.1. claims: 1-12

a conventional magnetic core comprising a plurality of magnetic segments separated by a plurality of gaps filled with an isolation medium (claim 12); a conventional transformer comprising said core (claims 1-11)

1.2. claims: 13, 14

a resonantly driven ignition system comprising a conventional transformer

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/IB2010/052679
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