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(54) **COLD ROLLED ELECTROMAGNETIC STEEL SHEET USED FOR RAPID CYCLING
SYNCHROTRON AND PRODUCING METHOD THEREOF**

(57) A cold rolled electromagnetic steel sheet for rapid cycling synchrotron, and a manufacturing method thereof, the method includes the steps of 1) smelting and casting, the composition of the cold rolled electromagnetic steel sheet is C 0.001~0.003 wt%, Si 0.60%~0.90 wt%, Mn 0.40%~0.70wt%, P≤0.04 wt%, Al 0.60~0.80 wt%, S≤0.0035 wt%, N≤0.003 wt%, and the rest is Fe; smelting and RH refining, and then casting to form semi-finished product; 2) hot rolling; 3) normalizing, in which the normalizing temperature is controlled between 960°C~980°C, and the normalizing time is 30~60s; 4) pickling and cold rolling; 5) annealing, wherein the annealing tem-

perature is controlled to be between 850°C~870°C, and the annealing time is 13~15s; 6) obtaining non-oriented silicon steel product after coating. The cold rolled electromagnetic steel sheet of the present invention has low coercivity, specifically in case that the magnetizing intense returns to zero after reaching 10 Oersted (Oe), the coercivity of the material is $H_c \leq 79.6$ A/m; high magnetic induction, which is $B_{50} \geq 1.75$ T; and low iron losses of $P_{15/50} \leq 4.2$ W/kg, and the iron losses after strain-annealing is $P_{15/50} \leq 3.5$ W/kg.

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Description

FIELD OF THE INVENTION

5 **[0001]** The present invention relates to a cold rolled electromagnetic steel sheet, particularly to a cold rolled electromagnetic steel sheet for rapid cycling synchrotron, and a manufacturing method thereof.

BACKGROUND

10 **[0002]** One of the important features of a rapid cycling synchrotron is that the magnetizing current operates in a DC-biased sinusoidal current state,; a rapid cycling synchrotron (RCS) with relative high energy is used to accelerate particles to increase the energy; and when a certain requirement for beam energy is obtained, it is drawn from a ring and scattered to a spallation target. Based on characteristics of the device, there are relative high requirements for the cold rolled electromagnetic steel sheets for manufacturing the magnet:

15 **[0003]** Low coercivity: when magnetizing intense returns to zero after reaching 10 Oersted (Oe), the coercivity of the material $H_c \leq 79.6$ A/m.

[0004] High electromagnetic induction: $B_{50} \geq 1.74$ T, with the controlling object of 1.75~1.76T; low iron losses: $P_{15/50} \leq 4.7$ W/kg, With the controlling object of 3.8~4.2 W/kg, and the iron losses after strain-annealing is $P_{15/50} \leq 3.5$ W/kg, with the controlling object of 2.8~3.2 W/kg.

20 **[0005]** Currently, in Japan, Europe and United States, the electromagnetic steel sheets for rapid cycling synchrotron are mainly manufactured by the following method:

[0006] 1. JP H05-247604 discloses a method of tempering (by critical reduction rate) extra-low carbon aluminum killed steel. The purpose of critical tempering is to coarsen the grain of the pure iron belt when the user carries out electromagnetic annealing, so that extra-low coercivity can be obtained. The drawbacks of the method are that since the critical reduction rate is relative large, which causes strain ageing, so that the hardness of the pure iron belt increases rapidly after being delivered. Thus, it will be difficult for the user to punch the iron belt. And, if the pure iron belt is annealed by a bell type furnace, the performance of the magnet will suffer fluctuation caused by the fluctuation of the pure iron belt in lengthwise.

30 **[0007]** 2. The rapid cycling synchrotrons in United States and Germany mainly use ordinary non-oriented electrical steel, such as M600-50A or M470-50A and so on. The product is obtained by the manufacturing method of smelting-continuous casting-hot rolling-pickling-cold rolling-annealing-coating. Although the product satisfies the requirements in terms of coercivity and iron losses, its electromagnetic induction is relative low, with B_{50} actual in the range of 1.69~1.72T, which directly affect the capacity of the rapid cycling synchrotron.

[0008] Thus, it can be seen that the drawbacks of the rapid cycling synchrotron caused by the present cold rolled electromagnetic steel sheets is that:

35 **[0009]** 1. The iron losses and the coercivity satisfy the requirements, but the electromagnetic induction is relative low.

[0010] The performance of the product can satisfy the requirements, but the processing prosperities and the stability are relative low.

40 SUMMARY

[0011] The purpose of the present invention is to provide a cold rolled electromagnetic steel sheet for rapid cycling synchrotron, and manufacturing method thereof, in order to obtain a cold rolled electromagnetic steel sheet with low iron losses, low coercivity and high electromagnetic induction. Namely, it has low coercivity, specifically when the magnetizing intense returns to zero after reaching 10 Oersted (Oe), the coercivity of the material is $H_c \leq 79.6$ A/m; high electromagnetic induction, which is $B_{50} \geq 1.75$ T; and low iron losses of $P_{15/50} \leq 4.2$ W/kg, and the iron losses after strain-annealing is $P_{15/50} \leq 3.2$ W/kg.

[0012] To fulfill the above purpose, technical solution of the present invention is as follows:

50 **[0013]** a cold rolled electromagnetic steel sheet for rapid cycling synchrotron, the composition of which is C 0.001~0.003 wt%, Si 0.60%~0.90 wt%, Mn 0.40%~0.70 wt%, $P \leq 0.04$ wt%, Al 0.60~0.80 wt%, $S \leq 0.0035$ wt%, $N \leq 0.003$ wt%, and the rest components are Fe and unavoidable impurities.

[0014] The method for manufacturing a cold rolled electromagnetic steel sheet for rapid cycling synchrotron according to the present invention includes the steps of:

55 **[0015]** 1) smelting and casting, wherein the composition of the cold rolled electromagnetic steel sheet is C 0.001~0.003 wt%, Si 0.60%~0.90 wt%, Mn 0.40%~0.70 wt%, $P \leq 0.04$ wt%, Al 0.60~0.80 wt%, $S \leq 0.0035$ wt%, $N \leq 0.003$ wt%, and the rest components are Fe and unavoidable impurities; carrying out smelting, RH refining according to the above mentioned components, and then casting the liquid steel to form semi-finished product, wherein when the RH refining is finished, the free oxygen in the liquid steel is lower than 25ppm;

[0016] 2) Hot rolling;

[0017] 3) Normalizing, in which the normalizing temperature is controlled to be between 960°C~980°C, and the normalizing time is 30~60s;

[0018] 4) Pickling and cold rolling;

[0019] 5) Annealing, in which the annealing temperature is controlled to be between 850°C~870°C, and the annealing time is 13~15s;

[0020] 6) Obtaining non-oriented silicon steel product after coating.

[0021] Further, average grain size in the steel sheet is more than 40 μ m, preferably is controlled to be between 40~50 μ m.

[0022] The design for the composition of the present invention is as follows:

[0023] Carbon of less than 0.003%, which is in the form of interstitial phase atom of iron based lattice cell, and strongly hinders the grain's growth, and in turn results in degradation of iron losses and coercivity. If the carbon exceeds 0.005%, decarburization will become difficult, and it will cause magnetic ageing, which results in substantial degradation in term of iron losses. Therefore, it is preferably to control the content of carbon to be lower than 0.003%.

[0024] Silicon of between 0.60%~0.90%, which is a vital alloy element of the electromagnetic steel sheet, and contributes to improve the resistivity, reduce eddy current losses, and reduce iron losses. If content of the silicon is too low, the iron losses will be degraded, and if the content of the silicon is too high, the processability of the electrical steel will be degraded, and the electromagnetic induction will decrease.

[0025] Manganese of 0.40%~0.70%, which mainly functions to increase resistivity, to reduce iron losses and meanwhile to change surface condition. If the content of the manganese is too high, it will make the following cold processes difficult, and if the content of the manganese is too low, the iron losses will increase, which results in hot brittle.

[0026] Phosphor of lower than 0.04%, which mainly functions to improve processability of the steel sheet. As the phosphor is a grain boundary polyvinylidene element, if its content is too high, the processability will be degraded, and the coercivity will rise at the same time.

[0027] Aluminum of 0.60%~0.80%, which is mainly for increasing resistivity, lowering iron losses, and decreasing the oxidized impurities during steel making, and further increasing electromagnetic induction and lowering coercivity. If the content of aluminum is too high, it will be difficult to carry out pouring during continuous casting, and result in decrease of electromagnetic induction, and if the content of aluminum is too low, the iron losses and the coercivity will be degraded.

[0028] Sulphur of less than 0.0035%. If the content of the sulphur is more than 0.0035%, precipitation amount of manganese sulfide will increase that intensively hinders grain growth, and the iron losses and coercivity will be degraded.

[0029] Nitrogen of less than 0.003%. If the content of the nitrogen is more than 0.003%, precipitation amount of aluminium nitride will increase that intensively hinders grain growth, and the iron losses and coercivity will be degraded.

[0030] In the manufacturing method of the present invention, when the RH refining process is completed, content of free oxygen in liquid steel is less than 25ppm. Thus, generally the oxidized impurities in the steel are reduced, and then the iron losses and coercivity are decreased effectively.

[0031] When the RH refining is completed, if content of free oxygen in liquid steel is more than 25ppm, the excessive free oxygen will act with the Si, Mn, P, Al in the steel to form a small quantity of three composition oxidized impurity of SiO₂-Al₂O₃-MnO, accompanied with slight amount of P₂O₅, so as to distort crystal lattice of the cured material, which results in increase of magnetostatic energy and magnetoelastic energy, and increase of domain wall motion resistance.

[0032] Meanwhile, during hot rolling under 1100°C~880°C, the three composition oxidized impurity of SiO₂-Al₂O₃-MnO possesses sound plasticity, so as to be rolled into chain-shape and bar-shape impurity. During cold rolling process, the three composition oxidized impurity of SiO₂-Al₂O₃-MnO presents brittleness characteristic, so that it can be easily rolled in a long string of particle-shaped impurities, i.e. forming composite oxidized impurities primarily of C-type impurity (chain-shape and bar shape) and secondarily of D-type impurity (dot-shaped). This results in difficulty of magnetizing, decrease of electromagnetic induction intense and increase of coercivity.

[0033] Deoxidizing intensity of metal elements differs from balance point of oxygen in steel, which in sequence shall be Al, Si, Mn. Therefore, during smelting, by controlling total amount of Si+Al at 1.2%~1.7%, the SiO₂-Al₂O₃ formed in the prophase of refining can be sufficiently removed from the steel. Meanwhile, when free oxygen is kept below 25ppm, and Mn in the steel is controlled to be 0.40%~0.70%, i.e. in an atmosphere of poor oxygen and rich manganese, production of the three compositions oxidized impurity of SiO₂-Al₂O₃-MnO is further reduced. Thus, the composition oxidized impurity primarily produced in the following processes of hot rolling and cold rolling, which is of C-type impurity (chain-shape and bar shape) and secondarily of D-type impurity (dot-shaped), can be reduced, so the grain growth is promoted, the electromagnetic induction is improved, and the coercivity is lowered.

[0034] For normalizing, the normalizing temperature is controlled to be between 960°C~980°C, and the normalizing time is 30~60s. The control of the normalizing temperature relates to Si, Mn, Al, N, C, S. The increase in the contents of Si, Al, Mn may help in lowering the normalizing temperature, but if the normalizing temperature is too low, and if the normalizing time is too short, accumulation and growth of the product precipitated from the steel will be negatively affected, which may result in decrease of the magnetic induction and degradation of iron losses and coercivity. If the contents of Si, Al, Mn is decreased, the normalizing temperature will be increased, but if the normalizing temperature is

too high, and if the normalizing time is too long, the loss on ignition of the steel will increase, part of the precipitated products from the steel, such as Mn, AlN and the like, are solid solved, which will result dispersion after cold rolling and annealing, so that carbon and nitrogen deposition will be precipitated, which will severely degrade the iron losses and coercivity. To this end, while the normalizing temperature is controlled, the contents of the sulphur and the nitrogen are required to be $S \leq 0.0035\%$ and $N \leq 0.003\%$.

[0035] For annealing, the annealing temperature is controlled to be between $850^{\circ}\text{C} \sim 870^{\circ}\text{C}$, and the annealing time is 13~15s. If the annealing temperature is too high, and if the annealing time is too long, average diameter of the grain will excessively large, thus the electromagnetic induction is lowered, and the processability degrades; while if the annealing temperature is too low, and if the annealing time is too short, the grain growth will be hindered, so that the iron losses and the coercivity are degraded, because of the presence of phosphor in the steel, which results in grain boundary polyvinylidene. To this end, when the annealing temperature is controlled, the content of P element is required to be $P \leq 0.04\%$.

[0036] The average grain size in the steel sheet is more than $40\mu\text{m}$, preferably is controlled to be between $40 \sim 50\mu\text{m}$. The grain size has certain relationship with the coercivity. If the grain is too small, the iron losses will increase, and the coercivity is relatively large. If the grain is too large, area occupied by the gain boundary will decrease, so that the coercivity will decrease at the same time, but the magnetic induction will further decreases.

[0037] Beneficial Effects of the Invention

[0038] 1. The present invention reduces the contents of the impure element and impurity, so as to further increase the magnetic induction, and lower the coercivity, by content-optimized proportioning and exploration on favorable elements, such as Si, Mn, Al. By preferred design for the normalizing process and annealing process, coarsening of the precipitated products and the grain is facilitated, so that the iron losses and the coercivity decreases, thus, a cold rolled electromagnetic steel sheet for rapid cycling synchrotron with low iron losses, low coercivity and high magnetic induction can be obtained. Provide solid guarantee in term of raw material for improving the technical level of rapid cycling synchrotron of our country, and broaden the way in product development.

[0039] 2. The product cost is competitive. The present invention carries out annealing and coating based on just one time of cold rolling, instead of applying the method of tempering (by critical reduction rate) extra-low carbon aluminum killed steel, such that the operation is simplified, and the cost is competitive.

DETAILED DESCRIPTION

[0040] The present invention will be described in detail below in reference to the embodiments,

[0041] The main composition of the steel used in the embodiments of the present invention and those in the comparative example are listed in table 1.

[0042] After liquid steel sequentially passes a converter, and then is RH refined and poured to form semi-finished product, it undergoes processes of hot rolling, normalizing, pickling, cold rolling, annealing and coating to obtain then a non-oriented electrical steel product. During such processes, the semi-finished produced is hot rolled to be a steel belt of 2.6mm, then the hot rolled steel belt of 2.6mm is normalized with the normalizing temperature being controlled at 970°C and the normalizing time being controlled to be 30~60s. The normalized steel belt is cold rolled to be a steel belt of 0.5mm, and then it is finally annealed and coated. The final annealing temperature after cold rolling is 850°C , and the annealing time is controlled to be 13~15s, and thereby a cold rolled electromagnetic steel sheet is obtained.

[0043] The index for the electromagnetic performance of the cold rolled electromagnetic steel sheet of the embodiments and those of the comparative examples are listed in table 2.

Table 1		(in wt%)						
	C	Si	Mn	Al	S	N	P	Fe
Embodiment 1	0.003	0.750	0.550	0.71	0.0030	0.0015	0.04	rest
Embodiment 2	0.001	0.760	0.600	0.72	0.0019	0.0017	0.01	rest
Embodiment 3	0.001	0.620	0.410	0.61	0.0028	0.0016	0.03	rest
Embodiment 4	0.002	0.860	0.690	0.78	0.0026	0.0018	0.02	rest
Embodiment 5	0.003	0.620	0.670	0.79	0.0029	0.0019	0.03	rest
Embodiment 6	0.003	0.860	0.420	0.62	0.0031	0.0023	0.01	rest
Embodiment 7	0.001	0.760	0.430	0.72	0.0029	0.0017	0.02	rest
Embodiment 8	0.002	0.760	0.680	0.61	0.0031	0.0016	0.04	rest

(continued)

Table 1		(in wt%)						
	C	Si	Mn	Al	S	N	P	Fe
Comparative example 1	0.001	1.450	0.250	0.35	0.0031	0.0016	0.03	rest
Comparative example 2	0.005	1.040	0.300	0.25	0.0029	0.0018	0.01	rest
Comparative example 3	0.002	0.750	0.250	0.25	0.0019	0.0015	0.02	rest
Comparative example 4	0.003	0.350	0.270	0.20	0.0034	0.0019	0.04	rest
Comparative example 5	0.003	0.760	0.600	0.72	0.0045	0.0017	0.05	rest
Comparative example 6	0.001	0.750	0.620	0.71	0.0041	0.0037	0.02	rest

Table 2

No.		Diameter of the grain (μm)	coercivity (A/M)	Electromagnetic Induction (T)	Iron Losses (W/kg)	Whether meet the requirement of using for rapid cycling synchrotron
Embodiments	1	46	69.4	1.755	4.03	yes
	2	48	61.5	1.757	3.92	yes
	3	43	72.6	1.754	4.12	yes
	4	49	60.7	1.758	3.86	yes
	5	45	68.7	1.756	3.98	yes
	6	44	71.6	1.752	4.06	yes
	7	43	73.8	1.753	4.13	yes
	8	42	75.3	1.752	4.15	yes
Comparative examples	1	58	47.8	1.689	3.81	no
	2	52	71.9	1.732	4.72	no
	3	41	83.6	1.735	5.21	no
	4	27	91.3	1.761	6.35	no
	5	39	79.8	1.739	4.57	no
	6	37	81.4	1.737	4.82	no

[0044] It can be seen from tables 1 and 2 that the index for the electromagnetic performance of the steel sheets obtained by the embodiments are significantly advantageous over those for the electromagnetic performance of the steel sheets obtained by the comparative examples, and the steel sheets of the embodiments completely satisfy requirements for usage in rapid cycling synchrotron.

[0045] In summary, based on the mechanism of the effects of various factors on the coercivity, iron losses, magnetic induction of the cold rolled electromagnetic steel sheet, the present invention discovers and optimizes the blending ratio of beneficial elements of Si, Mn, Al, and the like to reduce the contents of the impurities, on the basis of one time cold rolling, so that the magnetic induction is further improved. By preferred design for the normalizing process and annealing process, the coarsening of the precipitated products and the grain is facilitated, so that the iron losses and the coercivity decreases, thus, a cold rolled electromagnetic steel sheet for rapid cycling synchrotron with low iron losses, low coercivity and high magnetic induction is obtained.

[0046] The non-oriented electrical steel is applied in a device called China Spallation Neutron Source Rapid Cycling Synchrotron (CSNS/RCS), which belongs to The Institute of Modern Physics of Chinese Academy of Sciences. The

product has the characteristic of low iron losses and high magnetic induction. The successful applying of the present invention will provide solid guarantee in term of raw material for improving the technical level of rapid cycling synchrotron of our country, and broaden the way in product development.

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Claims

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1. A cold rolled electromagnetic steel sheet for a rapid cycling synchrotron, the composition of which is C 0.001~0.003 wt%, Si 0.60%~0.90 wt%, Mn 0.40%~0.70wt%, P≤0.04 wt%, Al 0.60~0.80 wt%, S≤0.0035 wt%, N≤0.003 wt%, the balance comprising Fe and unavoidable impurities.

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2. A method for manufacturing a cold rolled electromagnetic steel sheet for rapid cycling synchrotron according to claim 1, comprising the steps of:

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1) smelting and casting, wherein the composition of the cold rolled electromagnetic steel sheet is C 0.001~0.003 wt%, Si 0.60%~0.90 wt%, Mn 0.40%~0.70 wt%, P≤0.04 wt%, Al 0.60~0.80 wt%, S≤0.0035 wt%, N≤0.003 wt%, the balance comprising Fe and unavoidable impurities;

comprising carrying out smelting, RH refining under the said composition, and then casting liquid steel to form semi-finished product, wherein when the RH refining is finished, contents of free oxygen in the liquid steel is lower than 25ppm;

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2) hot rolling;

3) normalizing, in which the normalizing temperature is controlled between 960°C ~980°C, and the normalizing time is 30~60s;

4) pickling and cold rolling;

5) annealing, wherein the annealing temperature is controlled to be between 850°C~870°C, and the annealing time is 13~15s; and

6) obtaining a non-oriented silicon steel product after coating.

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3. The method for manufacturing a cold rolled electromagnetic steel sheet for a rapid cycling synchrotron according to claim 2, wherein the average size of grain in the steel sheet is more than 40μm.

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4. The method for manufacturing a cold rolled electromagnetic steel sheet for a rapid cycling synchrotron according to claim 2, wherein the average size of grain in the steel sheet is controlled to be between 40~45μm.

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INTERNATIONAL SEARCH REPORT

International application No.

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A. CLASSIFICATION OF SUBJECT MATTER

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:C21D8/-;C22C38/-

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 practicable, search terms used)

EPODOC, WPI, CNKI, CN-PAT, si,silicon,al, alumin?um,mn,manganese,magnetic,steel,electric+ steel, silicon steel, non-orient+, grain, size,cold roll+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP11286725A (NIPPON STEEL CORP) 19 Oct.1999 (19.10.1999) table 1,page 3	1
Y	table 1,page 3	2-4
Y	CN1887512A(BAOSHAN IRON & STEEL CO LTD)03 Jan.2007 (03.01.2007) description page 4, example 1, table 2	2-4
Y	JP11236618A (KAWASAKI STEEL CORP) 31 Aug.1999 (31.08.1999) column 6	4
Y	CN101041222A(BAOSHAN IRON & STEEL CO LTD)26 Sep.2007 (26.09.2007) description page 3, examples 2-7, table 2	2-4

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:	"I" 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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
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"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	

Date of the actual completion of the international search
29 Jun.2011 (29.06.2011)Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2011/072709

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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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2011/072709

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Form PCT/ISA /210 (patent family annex) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2011/072709

Continuation of: second sheet A. CLASSIFICATION OF SUBJECT MATTER:

C22C38/06 (2006.01)i

C21D8/12 (2006.01)i

REFERENCES CITED IN THE DESCRIPTION

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