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Title of invention:
METHOD OF CONTROLLED REMELTING OF OR LASER METAL FORMING ON THE SURFACE OF AN ARTICLE

Patentee:
Alstom Technology Ltd

Opponent:
SIEMENS AKTIENGESELLSCHAFT

Relevant legal provisions:
EPC Art. 56, 123(2)

Keyword:
Inventive step - (no)
Disclosure of amended feature (auxiliary request) - (no)

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Case Number: T 0633/10 - 3.2.06

D E C I S I O N
of the Technical Board of Appeal 3.2.06
of 14 November 2012

Appellant: (Patent Proprietor)	Alstom Technology Ltd Brown Boveri Strasse 7 5400 Baden (CH)
Representative:	Alstom Technology Ltd CHTI Intellectual Property Brown Boveri Strasse 7/699/5 5401 Baden (CH)
Respondent: (Opponent)	SIEMENS AKTIENGESELLSCHAFT Postfach 22 16 34 80506 München (DE)
Decision under appeal:	**Decision of the Opposition Division of the European Patent Office posted 28 January 2010 revoking European patent No. 1476272 pursuant to Article 101(3)(b) EPC.**

Composition of the Board:

Chairman: M. Harrison
Members: G. de Crignis
W. Sekretaruk

Summary of Facts and Submissions

I. European patent No. 1 476 272 was revoked by the opposition division with its decision posted on 28 January 2010.

II. The main request was held not allowable (Article 123(2) EPC) and the subject-matter of claim 1 of the first and secondary auxiliary requests was found to lack an inventive step (Article 56 EPC) in view of either

D5 US-A-6 024 792 or its family member
D15 EP-A-0 892 090
in combination with either one of

D4 DE-C-19 853 733;
D8 US-A-5 961 861; or
D21 G.R.B.E. Römer: "Modelling and Control of Laser Surface Treatment", Dissertation 1999.

III. The appellant (patent proprietor) filed an appeal against this decision and paid the appeal fee. On 1 June 2010 a statement setting out the grounds of appeal was received at the EPO together with a main request and two auxiliary requests.

IV. In a communication sent as an annex to a summons to oral proceedings, the Board commented on the relevance of D15 with regard to inventive step of the subject matter of claim 1 of all requests.

V. Oral proceedings were held on 14 November 2012.

The appellant requested that the decision under appeal be set aside and the European patent be maintained on the basis of the main request, filed 29 March 2010 or

on the basis of auxiliary request 1, filed 14 November 2012.

The respondent requested that the appeal be dismissed.

VI. Claim 1 according to the main request reads:

"A method of controlled laser remelting of the surface (5) of a single crystal (SX) or directionally solidified (DS) article (1), the method comprising the steps of

(a) moving a light source and a signal capturing apparatus and the article (1) relative to each other, thereby

(b) melting locally the surface (5) of the article (1) using the light source with a specific power for forming a melt pool (7),

(c) capturing an optical signal (13) from the melt pool (7) using the signal capturing apparatus,

(d) using the monitored optical signal (13) for the determination of temperature, temperature fluctuations, and the existing temperature gradient as properties of the melt pool (7),

(e) using the information of the temperature, temperature fluctuations, and the existing temperature gradient of the melt pool (7) from the optical signal (13) within a control system (16) in a feedback circuit to adjust as process parameters the laser power and/or the relative speed of the light source to article (1) by keeping the ratio G^n/V_s above a material dependant threshold value, G being the temperature gradient in the melt pool (7), n being a material constant, and V_S being the solidification speed, such that melt pool properties are obtained to avoid columnar to equiaxed transition (CET) during

solidification of the melt pool (7) and to avoid convection in the melt pool (7), and subsequently

(f) solidifying the melt pool (7)."

Claim 1 of Auxiliary Request 1 reads:

"A method of controlled laser metal forming on the surface (5) of a single crystal (SX) or directionally solidified (DS) article (1), the method comprising the steps of

(a) moving a light source and a signal capturing apparatus and the article (1) relative to each other, thereby

(b) melting locally the surface (5) of the article (1) using the light source with a specific power for forming a melt pool (7),

(c) capturing an optical signal (13) from the melt pool (7) using the signal capturing apparatus and a dichroitic mirror that transmits light from the light source and reflects light of the optical signal (13) or vice versa,

(d) injecting powder (8) with a carrier gas (9) into the melt pool (7) wherein the powder (8) injection is concentric with respect to the cone of captured optical signals (13) from the melt pool (7) and the cone of captured optical signals (13) from the melt pool (7) is concentric with respect to the light source focussing cone,

(e) using the monitored optical signal (13) for the determination of temperature, temperature fluctuations, and the existing temperature gradient as properties of the melt pool (7),

(f) using the information of the temperature, temperature fluctuations, and the existing temperature gradient of the melt pool (7) from the optical signal (13) within a control system (16)

in a feedback circuit to adjust as process parameters one or a combination of the power of the light source, the relative speed between the light source and the article (1), the mass feed rate of the added material and/or of the carrier gas (9) by keeping the ratio G^n/V_s above a material dependant threshold value, G being the temperature gradient in the melt pool (7), n being a material constant, and V_s being the solidification speed, such that melt pool properties are obtained to avoid columnar to equiaxed transition (CET) during solidification of the melt pool (7) and to avoid convection in the melt pool (7), and subsequently

(g) solidifying the melt pool (7)."

VII. The arguments of the appellant may be summarised as follows:

D15 was the closest prior art and disclosed a method for manufacturing monocrystalline structures. The energy input with the energy beam was regulated and/or controlled only in such a manner that the speed of solidification and the temperature gradient remained in the dendritic crystalline region in the GV diagram. Moreover, D15 disclosed the G^n/V_s curve only for one material (CMSX-4) and did not disclose how the control of the process should be carried out. The problem to control the process was known, although the solution of controlling it by using the temperature, temperature fluctuations and the existing temperature gradient of the melt pool was not recognized or suggested in any prior art document. The method of D15 differed further from the subject-matter claimed in that it always included the step of adding material to the melted

region of the substrate. Therefore, the subject-matter of claim 1 involved an inventive step.

D21 disclosed figures and description which related to a contour plot of the temperature distribution in the melting pool. However, the use of such data was not disclosed. The use of temperature related data for processing was also not disclosed in D4.

Marangoni convection was the "convection" referred to in claim 1, even if not *expressis verbis*. Avoidance of Marangoni convections was not mentioned in D15, nor was any method or means described for detecting its onset. In particular, avoidance of Marangoni convections related to temperature fluctuations which could not be determined from a G^n/V_s diagram. Hence, the control and regulation of the melting pool such that solidification velocity and temperature gradient lay in the dentritic crystalline area related only to one condition. A second condition was to avoid undesired recrystallisation germination in the melting pool which was obtained by the avoidance of Marangoni-convections. Increasing temperature fluctuations increased the creation of such Marangoni-convections. For obtaining monocrystalline material it was possible to create conditions which led to identical data points in the G^n/V_s diagram but which could nevertheless have a different degree of temperature fluctuation. The control of the energy delivery in a way that the solidification velocity and the temperature gradient remained in the dendritic crystalline area of the GV diagram did not include the monitoring of the temperature fluctuations in the melting pool. These considerations underlying the patent in suit had not been recognized before and therefore the subject-matter of claim 1 involved an inventive step.

Auxiliary request 1 should be admitted and was allowable. Its subject-matter was based upon originally filed claims 2, 5, 18, 16, 17 and upon passages in the description on pages 7, lines 28 to 30 and page 8, line 21 and page 9, line 29 and page 5, lines 3 to 5. Additionally, the detection of the onset of Marangoni convection via an optical signal was generally disclosed for such a method on page 10, lines 13 to 16.

VIII. The arguments of the respondent may be summarised as follows:

The subject-matter of claim 1 of the main request did not involve an inventive step. D15 disclosed such a method including a control and regulation without specifying such. The GV diagram in D15 implicitly disclosed that the control and regulation of the process had to be effected by determination and continuous on-line feedback on the basis of temperature data. Hence, the objective technical problem was to implement a suitable control and regulation for such a process. Each of D4 and D21 suggested the on-line use of continuous temperature data as means for the regulation and control of such a process. When continuously determining the temperature in the process, the assembled data necessarily had to be processed in order to verify that the temperature fluctuations and gradients remained in the desired range(s) and area. When linking such data by a feedback control with the further process means such as laser power and process speed, the skilled person would establish a process which avoided columnar to equiaxed transition during solidification of the melt pool.

The skilled person also knew that Marangoni-convection had to be avoided, which was acknowledged already in the patent in suit (paragraphs [0006/0007] of the B-publication) but no features were defined in the claim which should be used in order to control and regulate the process parameters in order to avoid such convection in the melt pool even though the appellant argued that temperature fluctuations were to be considered in this respect. Additionally, no disclosure reflecting a basis for this argument was present in the specification.

Auxiliary request 1 was not allowable. In particular the insertion of only part of the subject-matter of originally filed claim 5 into claim 1 led to an inadmissible intermediate generalisation. No feature in claim 1 defined, either explicitly or implicitly, the feature of claim 5 as originally filed that the thermo-physical properties of the deposit should match those of the article.

Moreover, the disclosure on page 8, lines 19 to 22 concerning the determination of the existing temperature gradient was related to an optical signal being "continuously" captured, whereas the disclosure of originally filed claim 15 included the capturing of the optical signal from the centre and vicinity of the light source focal spot by using an optical fiber or an imaging fibre bundle or a CCD camera. This capturing of the optical signal was required when considering the disclosure, but had been omitted from claim 1.

Reasons for the Decision

1. Main request

1.1 Interpretation of claim 1

Paragraph [0007] of the patent in suit refers to melt pool convection being affected by process parameters like mass feed rate, protection gas stream and injection angle and to Marangoni convection being only detectable with melt pool monitoring. Concerning the interpretation of claim 1 with regard to the feature "to avoid convection in the melt pool", the parties agreed with the conclusion of the Board that it only relates to Marangoni convection since generally it is impossible to avoid thermal convection.

Additionally, with regard to this feature, claim 1 does not include a method step beyond the one of capturing the optical signal from the melt pool and simply "using" the information of this signal for the determination of temperature, temperature fluctuations and the existing temperature gradient within a control system in a feedback circuit to adjust the process parameters accordingly. In this regard it is therefore important to note that when considering temperature fluctuations and gradient, such data all rely on the determination of the temperature and its changes, which determination has to be done continuously and has to be documented in relation to time and position in order to allow the calculation of fluctuations and gradients and in order to enable the control system to give immediate feedback for adjusting the power of the laser beam when necessary. Therefore, all in all, the information which is used in step (e) is the continuous determination of the temperature in dependency of time and position via

capturing an optical signal. Hence, steps (c), (d) and (e) of claim 1 are all linked in that they are based upon the continuous determination of the temperature which thus represents the "information" which is used in a control/feedback system.

With regard to the avoidance of Marangoni convection, the appellant considered the disclosure in the patent in suit on page 10, lines 13 to 18 as being relevant. However, such disclosure is not related to any further method step and thus does not alter the foregoing analysis.

Thus, since no further step is linked to the avoidance of Marangoni convection, such avoidance can only be understood as being inherent in any method which results in obtaining the desired type of crystal structure, which again is dependent on the GV diagram of the particular material being observed. In view of this interpretation of the feature "to avoid convection", no further method step has to be considered for the assessment of inventive step.

2. Main request - inventive step

2.1 D15 represents the closest state of the art. This was also not disputed by the parties. It discloses a method of controlled laser metal forming and remelting of the surface of a single or directionally solidified article. The GV diagram in Figure 1 discloses (for a particular material) the dependency of the solidification velocity on the temperature gradient and also how this influences globulitic or dendritic crystallisation. The method disclosed refers to the regulation and/or control of the energy input by means of the energy beam in such a manner that the speed of

solidification and the temperature gradient lie in the dendritic crystalline region in the GV diagram (abstract; claim 1; page 3, line 43 to page 5, line 34; page 6, lines 10 - 12). Hence, implicitly, a feedback system is necessary in order to provide the disclosed control and regulation of the laser energy continuously during the process.

2.2 Claim 1 concerns such a method of controlled laser remelting and includes a variety of method steps, designated with letters (a) to (f). The opposition division identified the subject-matter of claim 1 as differing from the disclosure in D15 in the following steps (see point 3.4.2.2 of the appealed decision):

- moving a capturing signal apparatus (part of step (a));
- capturing an optical signal from the melt pool using the signal capturing apparatus (step (c));
- using the monitored optical signal for the determination of temperature, temperature fluctuations, and the existing temperature gradient as properties of the melt pool (step (d));
- using the information of the temperature, temperature fluctuations, and the existing temperature gradient of the melt pool from the optical signal within a control system (part of step (e)).

2.3 The appellant considered this analysis as being incorrect and argued that further differences were present.

2.3.1 One further difference was alleged to concern the fact that D15 did not disclose a method without the addition

of further material, which was important since claim 1 defined "remelting", not "metal forming".

However, this argument is non-persuasive, since in claim 2 of the patent in suit, which is notably dependent on claim 1, the step of injecting powder or a wire into the melt pool is explicitly defined. Thus claim 1 clearly encompasses the addition of a further material. Accordingly the feature "remelting" does not represent a difference with regard to the disclosure in D15.

2.3.2 A still further difference was alleged to concern the fact that the feature "to avoid convection in the melt pool" would be a feature in addition to the step of "keeping the ratio G^n/V_S above a material dependant threshold value", since, for obtaining monocrystalline material it was allegedly possible to create conditions which led to identical data points in the G^n/V_S diagram but which could nevertheless have a different degree of temperature fluctuation whereby it was argued that such detail was disclosed in none of the cited documents because such problem had never been recognized.

However, no evidence has been provided that it would be possible to create such conditions and also - as set out under point 1 above - there is only one method step (step (e)) defined which concerns the use of the information of the data collected via determination of the temperature (also in the form of its processed data such as temperature fluctuations and the existing temperature gradient) of the melt pool via an optical signal. The claimed method step does not give any further instruction (and hence provides no further limitation) of how to create the required conditions other than remaining within the desired area in the $G^n/$

V_s diagram in order to avoid CET and to avoid Marangoni convection simultaneously. Hence, no particular or additional method step concerning the avoidance of such convection is present in claim 1. Also in the description (see paragraph [0007]) only a general hint is given to the skilled person to monitor process parameters (like mass feed rate, protection gas stream, injection angle) in this regard. Importantly, the claim (and indeed also the description) does not link the avoidance of convection to only the information related to temperature fluctuations, but to the use of the "information of" the temperature, temperature fluctuations, and the existing temperature gradient of the melt pool to adjust the process parameters. It is not specified which information specifically has to be used for avoiding such convection.

2.4 Concerning the aim of the invention disclosed in D15, this refers to the provision of a method by means of which it is possible to repair or recondition a monocrystalline or single crystal work piece (D15: col. 2, l. 12/15;). Hence, the object of D15 is consistent with that of the patent in suit, see paragraph [0001] of the patent in suit. Such object is generally relevant for single-crystal components like e.g. turbine blades and vanes which are expensive parts affected by local damage or local mechanical wear.

2.5 The features distinguishing the subject-matter of claim 1 from the disclosure in D15 (see point 1.2 above) all relate to the provision of a control system for obtaining the desired article. In the absence of any disclosure in D15 about how to provide a control system which allows adjusting the process parameters of the laser power and/or the relative speed of the light source to the article so as to remain on the dendritic

side of the GV diagram, the objective technical problem underlying the patent in suit can only be derived as being that of providing an appropriate control method to perform the method of D15.

2.6 In claim 1 of the patent in suit, the control method used is the capturing of an optical signal and using the monitored signal for the determination of the temperature and processing this data to use the time-related and position-related data (such as the temperature fluctuations and the temperature gradient) of the melt pool within a control system in a feedback circuit.

2.7 Hence, when starting from the process disclosed in D15, and desiring to find information about which parameter to monitor with regard to the structure of the finished article, the skilled person would consider the GV-diagram as being of the utmost relevance. This diagram, which is unique for each material, highlights that use of temperature parameters in any feedback system is of central importance.

2.8 The skilled person also knew how to establish temperature related data, at least from D21.

2.9 D21 discloses modelling and control for laser surface treatments. According to D21, page 18, lines 3 to 6, the objective of the control system is to obtain a constant temperature distribution in the surface layer and to obtain constant melt pool dimensions and characteristics (page 18, lines 3-6). The experimental set-up and process identification in D21 (Chapter 5) includes the use of two pyrometers and a thermal camera as sensors for feedback control (page 81, point 5.1). The control is related to the dynamic process model

which takes into account laser power, beam velocity and melt pool characteristics such as temperature and area. The variations in the melt pool temperatures are exemplarily shown in Figures 5.5 (a, b, c) which represent images obtained by the data of a thermal camera transformed into a contour plot (Figure 5.5.(b)) and into a diagram showing the isometric gray levels (Figure 5.5.(c)). The latter diagram allows the determination of the shape and dimension of the melt pool. Figures 5.5 (a, b, c) in combination with Table 5.5 also illustrate that temperature determinations were possible with a degree of accuracy suitable for determining $\Delta T/T$ to the third decimal place and demonstrate the dependency of the melt pool temperature and melt pool area on laser power when keeping the beam velocity constant.

2.10 Hence this disclosure suggests, to the skilled person, the monitoring of the temperature in the laser-material interaction zone by optical sensors, and the processing of such data (including the use of the temperature data in its derived values including gradients and fluctuations via the sensor(s) and comparators or a data base/expert system) in one or more control units for specifically providing the power and intensity profile needed for the laser beam (see Figures 3.2 and 3.8) in order to avoid disturbances in the process. Hence, when starting from the disclosure in D15 and combining it with the disclosure in D21, no inventive step can be attributed to the combination of features defined in claim 1. Thus, it is not necessary to discuss the further approach taking into consideration the disclosure of D4, since the subject-matter of claim 1 does not involve an inventive step as required under Article 56 EPC already for the reasons given.

3. Auxiliary request 1

3.1 Claim 1 includes the features of originally filed claims 2, 5, 16, 17 and 18 and further features of the originally filed description on page 5, lines 3 to 5; page 7, lines 28 to 30; page 8, line 21; page 9, line 29 and is - in the appellant's view - also supported allegedly by the disclosure on page 10, lines 13 to 18.

3.2 In originally filed claim 5, the feature "the forming on the surface of a single crystal (SX) or directionally solidified (DS) article (1)" is however linked to the step "of adjusting the melt pool properties to obtain epitaxial material build-up with thermo-physical properties of the deposit matched to those of the article (1)". No limitation defining such a requirement is however included in claim 1 of this request.

3.2.1 Although claim 1 includes the feature of avoiding CET during solidification of the melt pool and avoiding convection in the melt pool, such steps are carried out according to the claimed method via steps (e) and (f), which do not take into account the material characteristics of the injected powder but relate to the power of the light source, the velocity, the mass feed rate of the added material and/or the carrier gas, which should be adjusted accordingly. Hence, the amended claim does not include the step of adjusting the melt pool properties to obtain epitaxial material build-up with thermo-physical properties of the deposit matched to those of the article. Accordingly, claim 1 includes subject-matter extending beyond the content of the application as filed, contrary to Article 123 (2) EPC.

3.2.2 The appellant's reference to page 5, lines 3 to 5 does not change this finding in that this reference does not concern the thermo-physical properties of the deposit but indicates merely that it is possible to add new material without creation of grain boundaries under optimum process conditions. Accordingly, this disclosure could even be interpreted to have the meaning that any new material could be added under otherwise optimized process conditions and hence gives a meaning contrary to the one specified in originally filed claim 5.

3.2.3 The further reference by the appellant to page 7, lines 28-30 concerns the GV diagram which must also be known in order to identify the material dependent threshold value for obtaining an epitaxial solidification, i.e. without creating new grain boundaries. Such disclosure does not concern the thermo-physical properties of the deposit matched to those of the article.

3.2.4 The references of the appellant to page 8, line 21 and to page 9, line 29 concern the determination of the temperature data of the melt pool. Such determination can be carried out without any link to the thermo-physical properties of the deposit.

3.2.5 The further reference of the appellant to the disclosure on page 10, lines 13 to 18 does not concern the thermo-physical properties of the deposit either. Such disclosure refers to the monitored optical signal from the melt pool as allowing "to detect the onset of marangoni convection". As set out in the background of the invention (page 3, lines 6 to 15), the skilled person was aware of the onset of (marangoni) convection in the melt pool being "one of the main reasons for the

undesired CET"; accordingly melt pool monitoring was mandatory. However, no particular aspect of the melt pool characteristics is disclosed with regard to the thermo-physical properties of the deposit material.

3.2.6 Additionally it has to be taken into account that originally filed claim 5 was dependent only on the method of claim 2 which neither included the now claimed step concerning concentric powder injection nor the claimed features concerning the use of a dichroitic mirror for light transmission, the use of the monitored optical signal for the determination of a temperature gradient nor the use of such information within a control system in a feedback circuit. Moreover the method of originally filed claims 2 and 5 was not even linked to a particular ratio G^n/Vs.

3.3 Hence, there is no disclosure in the originally filed application of a method including the step of a dichroitic mirror transmitting light from the light source and reflecting light of the optical signal linked to the use of information to determine temperature gradients in the melt pool. There is also no disclosure of a method including such features in combination with the powder injection being concentric with respect to the cone of the captured optical signals.

3.4 Without any disclosure in the application as filed unambiguously indicating that such combinations of features were to be considered at all, claim 1 of the first auxiliary request contravenes Article 123(2) EPC.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

M. H. A. Patin M. Harrison

Decision electronically authenticated