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(54) **Title:** METHOD FOR MANAGING COATING GLOSS ON A COIL-COATING LINE

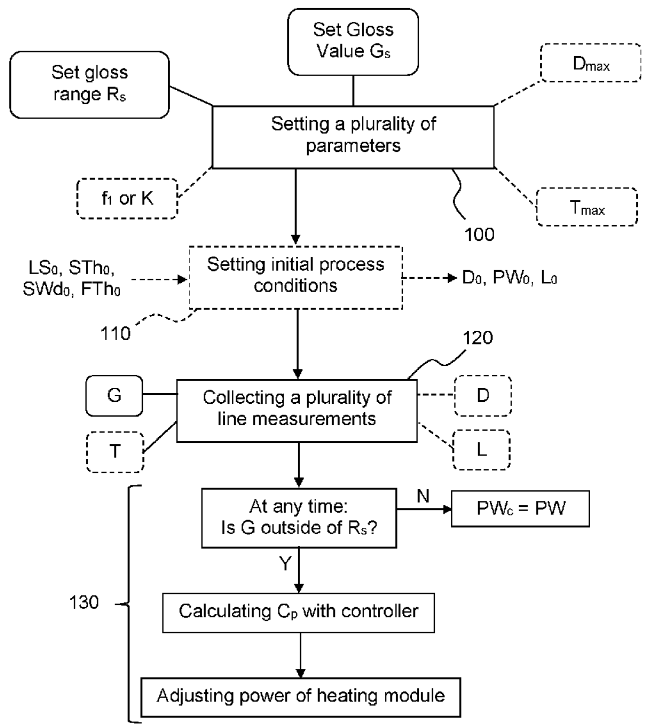

Figure 2

(57) **Abstract:** The invention relates to a method for managing the gloss of an organic coating formed on a moving strip on a coil-coating line comprising sequentially a paint applicator, a heating device comprising a heating module, an Ultra-Violet curing device and an Electron-Beam curing device, the method comprising correcting a deviation of the measured gloss G beyond a set gloss range Rs, the correction comprising a sub-step of calculating the correction CP to be applied to the power of the heating module, taking into account Gs and the measured gloss G, with a closed-loop controller and a sub-step of adjusting a setting of the coil-coating line taking into account the calculated correction CP.

WO 2024/209247 A1

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Method for managing coating gloss on a coil-coating line

The present invention relates to a method for managing the gloss of an organic coating applied on a moving strip on a coil-coating line. In particular, the moving strip is a metallic-coated steel strip.

Coil coating is a continuous, automated process for coating metal before fabrication into end products. The steel or aluminum substrate is delivered in coil form from the rolling mills. The metal coil is positioned at the beginning of the coil-coating line, and in one continuous process, the coil is unwound, pre-cleaned, pre-treated, pre-primed, and prepainted before being recoiled on the other end and packaged for shipment.

The product obtained by this process is a prepainted metal, also referred to as coil-coated metal, prefinished metal or pre-coated metal. It is commonly used in construction applications as well as appliances.

The paints traditionally used for coil-coating are solvent-based paints. Nevertheless, there have been a recent interest in radiation curing, which is the curing of materials using ultraviolet (UV processes) or electron beam (EB curing processes). The corresponding paints, known as radcure paints, are solvent-free and the curing process is triggered by either exposure to a high-energy UV light, possibly in conjunction with suitable photoinitiators, or exposure to accelerated electrons. Photoinitiators absorb UV light and generate free radicals. The latters react with double bonds of monomers causing chain reaction and polymerization. For UV-C and electron beam (EB) curing, initiators are not required. The high radiant energy produces sufficient reactive species (radicals) for polymerization to proceed spontaneously.

One of the specificities of radcure paints is to generate organic coatings with a high gloss due to high tension of the coating surface. To reduce this gloss and reach the requirements of the pre-painted markets (gloss typically between 15 and 30 GU for the construction market) paint suppliers add matting agents, as for solvent-based paints. However, the radcure paints being quite viscous due to the absence of solvent, only small amounts of matting agent can be added and it does not allow for low gloss levels. In addition, the migration of matting agents to the coating surface to achieve the desired gloss level is also very limited due to the speed of the curing process of radcure paints compared to solvent-based paints (1-2 seconds versus 12-25 seconds).

One way to mitigate this problem is known from WO81/00683 which discloses a curing process wherein the coating is first irradiated with curing radiation of wavelengths to which the coating is responsive but having substantially no distribution beneath about 300 nm (such as UV), and is subsequently irradiated with curing radiation of wavelengths to which the coating is responsive including substantial radiation at wavelengths beneath 300 nm (such as EB). This double curing is known as dualcure. Gloss control is obtained by adjusting on-line parameters including the spectral distribution, the intensity, or the dose of the initial radiation, or the time interval between the initial and subsequent irradiation steps.

It has nevertheless been observed that these on-line parameters are not enough to manage the gloss efficiently and in a reproducible way.

The aim of the present invention is therefore to remedy the drawbacks of the process of the prior art by providing a method for managing, efficiently and in a reproducible way, the gloss of an organic coating formed by application and curing of a wet film of a radcure paint on a moving strip on a coil-coating line.

For this purpose, a first subject of the present invention consists of a method for managing the gloss of an organic coating formed by application and curing of a wet film of a radcure paint on a moving strip on a coil-coating line comprising, sequentially along the path P of the moving strip, a paint applicator, a heating device comprising heating module, an Ultra-Violet curing device and an Electron-Beam curing device, the method comprising the steps of:

- Setting a set gloss value G_s of the organic coating and a set gloss range R_s of the gloss of the organic coating,
- Collecting the measure of the gloss G of the organic coating in the at least a width portion downstream of the Electron-Beam curing device,
- Correcting a deviation of the measured gloss G beyond the set gloss range R_s, this correcting step comprising a sub-step of calculating the

correction C_P to be applied to the power of the heating module, taking into account G_s and the measured gloss G, with a closed-loop controller and a sub-step of adjusting a setting of the coil-coating line taking into account the calculated correction C_P.

The method according to the invention may also have the optional features listed below, considered individually or in combination:

- the closed-loop controller is a proportional integral derivative controller,
- the correction C_P is a function of the difference between G_s and the measured gloss G,
- the correction C_P to be applied to the power of the heating module is calculated according to equation 1:

$$C_P(t) = K_p e_1(t) + K_i \int_0^t e_1(\tau) d\tau + K_d \frac{de_1(t)}{dt} \qquad (1)$$

where K_p is the proportional gain, K_i is the integral gain, K_d is the derivative gain and e_1 is the difference between G_s and the measured gloss G.

- The method further comprises an initial line setting step wherein:
    - a plurality of process parameters and/or of specifications of the strip are collected,
    - at least one initial line condition among the initial power PW_0 of the heating module, the initial UV dose D_0 of the Ultra-Violet curing device and the initial length L_0 between the Ultra-Violet curing device and the Electron-Beam curing device is set, taking into account the process parameters and/or specifications of the strip that have been collected,
- the collecting step further comprises collecting the measure of the temperature T of the wet film in at least a width portion of the moving strip upstream of the Ultra-Violet curing device,
- the correcting step further comprises a sub-step of calculating the corrected temperature T_c to be reached by the wet film, in the at least a width portion downstream of the heating module and upstream of the Ultra-Violet curing device,
- the corrected temperature T_c is calculated according to equation 2:

$$T_c = f_1 (T, G, G_s) \qquad (2)$$

where function f_1 of a predefined mathematical relation between the temperature of the wet film before Ultra-Violet curing and the gloss of the organic coating after Electron-Beam curing,

- the corrected temperature T_c is calculated according to equation 3:

$$T_c = T + K (G – G_s) \qquad (3)$$

- the correction C_P is a function of the difference between T_c and the measured temperature T,
- the correction C_P to be applied to the power of the heating module is calculated according to equation 4:

$$C_P(t) = K'_p e_2(t) + K'_i \int_0^t e_2(\tau)d\tau + K'_d \frac{de_2(t)}{dt} \qquad (4)$$

where K'_p is the proportional gain, K'_i is the integral gain, K'_d is the derivative gain and e_2 is the difference between T_c and the measured temperature T.

- the sub-step of adjusting a setting of the coil-coating line comprises adjusting the power of the heating module by the correction C_P,
- the Ultra-Violet curing device comprises a UV module,
- the setting step further comprises setting a maximum temperature T_{max} for the radcure paint,
- the collecting step further comprises collecting the UV dose D of the UV module,
- the sub-step of adjusting a setting of the coil-coating line comprises:
  - Evaluating if T_c is superior to T_{max},
  - If not, adjusting the power of the heating module by the correction C_p,
  - If T_c is superior to T_{max}:
    - calculating the correction C_D to be applied to the UV dose to which the wet film in the at least a width portion must be exposed in the UV module according to equation 5:

$$C_D = f_2 (G, G_s) \qquad (5)$$

    - adjusting a setting of the coil-coating line other than the power of the heating module, taking into account the calculated correction C_D.

- the sub-step of adjusting a setting of the coil-coating line other than the power of the heating module comprises adjusting the power of the UV module so that the wet film in the at least a width portion of the moving strip is exposed to the corrected UV dose $D_c = D + C_D$,
- the UV module is movable along the path P,
- the setting step further comprises setting a maximum UV dose D_{max} to which the wet film can be exposed in the UV module,
- the collecting step further comprises collecting the length L between the UV module and the Electron-Beam curing device,
- the sub-step of adjusting a setting of the coil-coating line other than the power of the heating module comprises:
    - Evaluating if $D + C_D$ is superior to D_{max},
    - If not, adjusting the power of the UV module so that the wet film in the at least a width portion of the moving strip is exposed with the corrected UV dose $D_c = D + C_D$,
    - If $D + C_D$ is superior to D_{max}:
        - calculating the correction C_L to be applied to the length between the UV module and the Electron-Beam curing device according to equation 6:

          $$C_L = f_3 (G, G_s) \qquad (6)$$

        - adjusting a setting of the coil-coating line other than the power of the heating module and than the power of the UV module, taking into account the calculated correction C_L.
- the sub-step of adjusting a setting of the coil-coating line other than the power of the heating module and than the power of the UV module comprises adjusting the length between the UV module and the Electron-Beam curing device to the corrected length $L_c = L + C_L$ so that the gloss of value G_s is obtained on the organic coating in the at least a width portion of the moving strip downstream of the Electron-Beam curing device.

A second subject of the invention consists of a coil-coating line comprising sequentially a paint applicator, a heating device comprising a heating module, an

Ultra-Violet curing device and an Electron-Beam curing device, the coil-coating line further comprising a gloss management tool for managing the gloss of an organic coating formed by application and curing of a wet film of a radcure paint on a moving strip on the coil-coating line, the gloss management tool comprising:

- a setting module setting a set gloss value G_s of the organic coating and a set gloss range R_s of the gloss of the organic coating,
- an acquisition module collecting the measure of the gloss G of the organic coating in the at least a width portion downstream of the Electron-Beam curing device,
- a correction module correcting a deviation of the measured gloss G beyond the set gloss range R_s, the correction comprising a sub-step of calculating the correction C_P to be applied to the power of the heating module, taking into account G_s and the measured gloss G, with a closed-loop controller and a sub-step of adjusting a setting of the coil-coating line taking into account the calculated correction C_P.

Other characteristics and advantages of the invention will be described in greater detail in the following description.

The invention will be better understood by reading the following description, which is provided purely for purposes of explanation and is in no way intended to be restrictive, with reference to:

- Figure 1, which is a schematic representation of a coil-coating line,
- Figure 2, which is a flowchart of a first embodiment of the method according to the invention,
- Figure 3, which is a flowchart of a second embodiment of the method according to the invention,
- Figure 4, which is a flowchart of a third embodiment of the method according to the invention.

It should be noted that spatially relative terms such as “upstream”, “downstream”, “lower”, “upper”, “above”, “below”, “before”, “after”... as used in this application refer to the positions and orientations of the different constituent elements of the coil-coating line.

The method according to the invention is intended for strips, such as metallic strips. Steel, either carbon steel or stainless steel, aluminium, copper are examples of metallic strips. In particular, steel strips can be bare or coated with a metallic coating, on either one or two sides of the strip. Examples of possible metallic coated steels are galvanized steel, steels coated with a zinc alloy comprising 5 wt.% of aluminum (Galfan®), steels coated with a zinc alloy comprising 55 wt.% of aluminum, about 1.5 wt.% of silicon, the remainder consisting of zinc and inevitable impurities due to the processing (Aluzinc®, Galvalume®), steels coated with an aluminum alloy comprising from 8 to 11 wt.% of silicon and from 2 to 4 wt.% of iron, the remainder consisting of aluminum and inevitable impurities due to the processing (Alusi®), steels coated with a layer of aluminum (Alupur®), steels coated with a zinc alloy comprising 0.5 to 20% of aluminium , 0.5 to 10% of magnesium, the remainder consisting of zinc and inevitable impurities due to the processing, steels coated with an alloy comprising aluminium, magnesium, silicon, possible additional elements, the remainder consisting of zinc and inevitable impurities due to the processing.

The method according to the invention is also intended for radcure paints. The term “radcure paints” refers to radiation curable compositions that are “cured”, or dried, utilizing short wavelength ultraviolet (UV) light and/or high-energy electrons from electron-beam (EB) sources. They usually comprise liquid monomers and oligomers, into which pigments, fillers, additives, photoinitiators can be dispersed, generally without the need for either solvent or water. They are thus substantially solvent-free. Radcure paints for dualcure preferably comprise acrylate or methacrylate monomers and photoinitiators.

With reference to Figure 1, the coil-coating line 1 according to the invention mainly comprises, sequentially along the path P of the moving strip, a paint applicator 2, a heating device 3 comprising a heating module, an Ultra-Violet curing device 4 and an Electron-Beam curing device 5.

The path P is the path followed by the strip S from its entry in the coil-coating line to its exit. It has a width and a length. Pieces of equipment are positioned along this path to perform operations on the strip.

A paint applicator 2 is a device that apply a wet film of paint on one or both sides of a strip with a set thickness of paint. In particular, its purpose is to apply the wet film of radcure paint. In the context of the invention, the technology of the paint applicator is not limited.

According to a variant of the invention, the paint applicator 2 is a paint roll-coater. It is an automated machine that coat one or both sides of a strip with rotating rolls. It is designed so that the strip passes through the machine that applies a layer of paint to one or both sides of the strip. There are numerous designs of paint roll-coaters depending on the configuration of the coil-coating line, the types of paints being used, and the types of strips being coated. The person skilled in the art will know which design is best adapted to each case. Generally speaking, the paint roll-coater comprises a paint pan, a steel or ceramic pick up roll, and a rubber covered coating roll. The purpose of the paint pan is to contain, circulate and preferably heat the paint. The pick up roll can be partially immersed in the paint and can rotate in either a clockwise or a counter clockwise direction to pick the paint up and transfer it to the coating roll. The latter transfers the paint to the strip.

According to another variant of the invention, the paint applicator 2 is a curtain coater. In that case, a curtain of paint is applied to the horizontal strip normally transverse to the curtain. The paint falls from a height under gravity from a curtain die or cascade while the strip is supported on a backing roller. This method is capable of achieving high line speeds and multilayer coatings.

Examples of other paint applicators are knife coater, dip or meniscus coater, slot coater, meter rod coater, slide coater.

The paint is usually applied with the paint applicator on the full width of the strip. By default, the width of the wet film of paint, and consequently of the organic coating, is the same as the strip width.

The paint applicator 2 is preferably equipped with at least one paint heating device suitable for heating and maintaining the paint at a set temperature. Heating the paint facilitates its application. It also further eases the gloss management as it minimizes the energy requirements at the level of the heating module and thus minimizes the inertia of the heating module. In the case of a paint roll-coater, the paint heating device can be a pan heater, i.e. a heater positioned in or around the paint pan. It can also be a temperature-controlled roll, in particular a temperature-controlled pick-up roll, possibly in combination with the pan heater. In the case of a curtain coater, the paint heating device can be a heater positioned upstream of the curtain die. It can also be a temperature-controlled backing roll, possibly in combination of the heater.

The paint applicator 2 is preferably equipped with a temperature measuring device for measuring the paint temperature and/or the wet film temperature at the level of the paint applicator. The temperature device can be, for example, a temperature sensor, a pyrometer, a thermal camera.

The coil-coating line 1 further comprises a heating device 3 comprising a heating module, positioned, along the path P of the moving strip, downstream of the paint applicator 2 and upstream of the Ultra-Violet (UV) curing device 4. Its purpose is to heat the wet film of radcure paint. The heating device further improves the temperature control of the wet film of paint before its surface is cured in the UV curing device. As the temperature of the strip exiting the paint applicator decreases at a rate that depends on a number of parameters (strip nature, strip width, strip thickness, line speed…), the temperature of the wet film entering the UV curing device may vary significantly from time to time, which would impact the gloss detrimentally. Thanks to the heating device, the temperature of the wet film can be very rapidly adjusted.

The heating device is preferably chosen among an infrared heater, an induction heater, a convector, a forced-air heater, a water spray heater, a water-air fog spray heater and a heated roll. Preferably the heating device is an infrared heater. In the case of water-based heaters, as the wet film of radcure paint is applied on the top side of the strip, water is preferably put in contact with the back side of the strip only.

According to one variant, the heating device is made of one heating module covering the full width of the path P of the moving strip. In that case, the wet film is heated uniformly along its width when passing (through) the heating device.

According to another variant, the heating device 3 comprises a plurality of heating modules distributed in the width of the path P. In other words, the plurality of heating modules forms a row substantially parallel to the width of the path P, i.e. perpendicular to the moving direction of the strip. For the sake of clarity, the heating modules described here are independent of each other and positioned adjacent to each other but they can be physically inseparable from each other. They can be individually-controllable portions of a single heating device.

The heating modules are preferably chosen among an infrared heater, an induction heater, a convector, a forced-air heater, a water spray heater, a water-air fog spray heater and a width portion of a heated roll. Preferably the heating modules are infrared heaters.

Thanks to this design, temperature variations in the strip width can be corrected and minimized. Preferably, the temperature variation of the wet film in the strip width at the exit of the heating device is below 1°C. It improves the gloss homogeneity of the coating in the strip width.

According to another variant, the heating device 3 comprises sequentially along the path of the moving strip a base heater covering the full width of path P and the plurality of heating modules described above. The base heater can be an infrared heater or an inductor. Thanks to this design, a part of the energy needed to reach the correct temperature of the wet film at the exit of the heating device is provided by the base heater. Each heating module of the plurality of heating modules independently provides the remaining part of the energy and can adjust it as requested.

The heating device 3 is preferably positioned above the path P so that the wet film applied on the top side of the strip is directly heated. The heating device can also be positioned above and below the path P to minimize thermal gradients.

The coil-coating line 1 further comprises an Ultra-Violet (UV) curing device 4. The purpose of this equipment is to cure the surface of the wet film of radcure paint. It has been observed that this surface curing generates a very fine texturing at the film surface which, combined with mating agents and possible other charges, contribute to the gloss of the organic coating once the wet film has been fully cured by Electron-Beam.

According to one variant, the UV curing device 4 covers the full width of the path P of the moving strip. In that case, the surface of the wet film is cured uniformly along the strip width when exposed to UV.

According to another variant, the UV curing device 4 comprises a plurality of UV modules distributed in the width of the path P. In other words, the plurality of UV modules forms a row substantially parallel to the width of the path P, i.e. perpendicular to the moving direction of the strip. For the sake of clarity, the UV modules described here are independent of each other and positioned adjacent to each other but they can be physically inseparable from each other. They can be individually-controllable portions of a single UV curing device.

Thanks to this design, different width portions of the path/strip can be exposed to different UV doses. It helps correcting and minimizing gloss variations in the strip width. Accordingly, the heating device preferably comprises a plurality of heating modules forming a row substantially parallel to the width of the path P, each heating module been suited for heating a width portion of the strip which is then exposed to the UV of one UV module. In other words, each width portion covered by a given UV module corresponds to the width portion covered by a corresponding heating module.

UVA and UVB are preferred. UVA is long-range UV radiation between 320 and 400nm. UVB is short-wave UV radiation between 280 and 320nm. They can be obtained with conventional arc UV lamps.

The UV curing device 4 is preferably movable along the path P of the moving strip. It allows the length between the UV curing device and the EB curing device to be adjusted, i.e. extended or shortened. It has indeed been observed that the wrinkles or surface roughness initiated during the UV curing is further developed during the time interval between UV curing and EB curing, which impacts the gloss of the organic coating.

In the case of a plurality of UV modules, each UV module is preferably movable along the path P independently of the others.

The coil-coating line 1 further comprises an Electron-Beam curing device 5. The purpose of this equipment is to cure the wet film of radcure paint, i.e. in its full thickness. It further freezes the surface roughness which appears at the surface of the wet film during UV curing and which further develops during the time interval between UV curing and EB curing. The EB device is generally operated in the following conditions: 100-200kV, 20-50kGy, inerting with nitrogen below 200ppm O_2.

Preferably, the coil-coating line 1 further comprises a wet film temperature measuring device 6 positioned downstream of the heating device 3 and upstream of the UV curing device 4. This wet film temperature measuring device measures the temperature of the wet film before it enters the UV curing device. It can measure the temperature of the wet film along the whole width of the path P of the moving strip or it can measure the temperature on only a portion of the width. Examples of wet film temperature measuring devices are pyrometer, thermal camera, thermocouple. The measured temperature can be expressed in °C, °F or K.

In the case where the wet film temperature measuring device measures the temperature on only a portion of the width, the measure on this portion can be considered relevant enough to manage the gloss of the whole strip width.

Alternatively, a plurality of wet film temperature measuring devices is positioned downstream of the heating device 3 and upstream of the UV curing device so that the whole width of the path P of the moving strip is covered. They form a row substantially parallel to the width of the path P. Accordingly, the heating device preferably comprises a plurality of heating modules forming a row substantially parallel to the width of the path P, each heating module been suited for heating a width portion of the strip whose temperature is then measured by one wet film temperature measuring device.

In order to further increase the temperature control of the wet film in the UV curing device, the wet film temperature measuring device 6 and the UV curing device 4 are not separated by more than 2 meters, preferably not by more than 1 meter, or the temperature of the wet film is not measured more than 4 seconds before the wet film is cured in the UV curing device, preferably not more than 2 seconds. Alternatively or in addition, the portion of the path P of the moving strip between the wet film temperature measuring device and the UV curing device can be thermally insulated to keep the wet film at the measured temperature before it is cured in the UV curing device.

The coil-coating line 1 further comprises a gloss measuring device 7 positioned downstream of the Electron-Beam curing device 5. This gloss measuring device measures the gloss of the organic coating after EB curing. It can measure the gloss of the organic coating along the whole width of the path P of the moving strip or it can measure the gloss on only a portion of the width. Examples of gloss measuring devices are glossmeters. The measured gloss is preferably expressed in GU (Gloss Units). The gloss is preferably measured in accordance with standards ISO 2813:2014 and EN 13523-2:2021. Preferably, the gloss is measured with a 20° geometry, a 60° geometry or a 85° geometry, i.e. the reflection angle is either 20°, 60° or 85°. More preferably, the gloss is measured with a 60° geometry.

In the case where the gloss measuring device measures the gloss on only a portion of the width, the measure on this portion can be considered relevant enough to manage the gloss of the whole strip width.

Alternatively, a plurality of gloss measuring devices is positioned downstream of the EB curing device so that the whole width of the path P of the moving strip is covered. They form a row substantially parallel to the width of the path P. Accordingly, the heating device preferably comprises a plurality of heating modules forming a row substantially parallel to the width of the path P, each heating module been suited for heating a width portion of the strip whose gloss is then measured by one gloss measuring device. Accordingly, the UV curing device preferably comprises a plurality of UV modules forming a row substantially parallel to the width of the path P, each UV module been suited for exposing to UV a width portion of the strip whose gloss is then measured by one gloss measuring device.

The coil-coating line 1 is preferably equipped with a strip speed measuring device, more preferably positioned at the level of a guiding roll. An example of strip speed measuring device is a tachymeter integrated on roll axis.

The coil-coating line 1 can further comprise an inductor 8 upstream of the paint applicator 2. It can heat the strip before it reaches the paint applicator. Having a warm strip in the paint applicator favors the paint application. Furthermore, the temperature reached by the strip in the inductor can be adjusted to correct possible gloss deviations, as it will be described in details later.

The coil-coating line 1 can further comprise an entry section with an uncoiler 9 to uncoil the strip to be coated on the line. The uncoiler can be combined with a welding machine or a stitching machine so that the front end of the strip to be coated can be attached to the tail end of the previous strip.

Alternatively, the coil-coating line can be coupled to a galvanizing line so that the strip coated with the metallic alloys contained in the bath of the galvanizing line is directly coated with the organic coating without having to first coil it and then uncoil it.

The coil-coating line 1 can further comprise an entry accumulator 10 located in the entry section of the line, downstream of the uncoiler if applicable. The accumulator is a piece of equipment that “accumulates” a certain amount of strip. It is a set of upper and lower banks of rolls through which the metal strip is threaded in a serpentine fashion, and it stores lengths of metal as the two roll banks are spread apart. The total stored length of metal depends on the design speed of the line, usually 60 seconds of steady-state metal processing time. When the entry section of the coil-coating line stops, the roll banks move toward each other, and the stored metal in the accumulator continues to feed the rest of the coil-coating line.

The coil-coating line 1 can further comprise a cleaning section 11, positioned downstream of the entry section, in particular downstream of the entry accumulator if applicable. In this section, the strip is subjected to a surface preparation step. This type of preparation comprises at least one step selected among rinsing, degreasing and a conversion treatment. The purpose of the rinsing is to eliminate the loose particles of dirt, potential residues of conversion solutions, soaps that may have formed and to achieve a clean and reactive surface. The purpose of the degreasing is to clean the surface by removing all traces of organic dirt, metallic particles and dust from the surface. Preferably, the degreasing is performed in an alkaline environment. The conversion treatment includes the application on the strip of a conversion solution that reacts chemically with the surface and thereby makes it possible to form a conversion layer. The latter increases the adherence of the paint and the corrosion resistance. The conversion treatment is preferably an acid solution that does not contain chromium. More preferably, the conversion treatment is based on hexafluorotitanic acid or hexafluorozirconic acid.

The coil-coating line 1 can further comprise a primer section, upstream of the paint applicator 2 and downstream of the cleaning section if applicable. In this section, a first layer of paint can be applied on the strip to form a primer coating. The primer section can comprise a primer paint applicator and a curing equipment. Depending on the nature of the primer, the curing equipment can be an oven, such as a convection oven, an infra-red (or near infra-red) oven or an induction oven, a UV curing device and/or an EB curing device.

The coil-coating line 1 can further comprise an exit accumulator 12 located in the exit section of the line, downstream of the EB curing device. The exit accumulator is similar to the entry accumulator described above.

The coil-coating line 1 can further comprise a recoiler 13 to recoil the strip which has been coated on the line. The recoiler can be combined with a cut-off to separate the strip from the next one processed on the line.

The invention also relates to a gloss management tool for managing the gloss of an organic coating formed by application and curing of a wet film of a radcure paint on a moving strip on a coil-coating line 1 comprising, sequentially along the path P of the moving strip S, a paint applicator 2, a heating device 3 comprising a heating module, an Ultra-Violet curing device 4 and an Electron-Beam curing device 5.

The gloss management tool comprises a setting module for setting a set gloss value G_s of the organic coating and a set gloss range R_s of the gloss of the organic coating.

The gloss management tool further comprises an acquisition module configured for collecting the measure of the gloss G of the organic coating in the at least a width portion downstream of the Electron-Beam curing device. Preferably, the acquisition module is further configured for collecting the measure of the temperature T of the wet film in at least a width portion of the moving strip downstream of the heating module and upstream of the Ultra-Violet curing device.

The gloss management tool further comprises a correction module configured for correcting a deviation of the measured gloss G beyond the set gloss range R_s, the correction comprising a sub-step of calculating the correction C_P to be applied to the power of the heating module, taking into account G_s and the measured gloss G, with a closed-loop controller and a sub-step of adjusting a setting of the coil-coating line taking into account the calculated correction C_P.

The gloss management tool can include a processing unit formed for example of a memory and of a processor coupled to the memory. The electronic monitoring device may also include a display screen and input/output means, such as a keyboard and a mouse, each being connected to the processing unit. Each of the setting module, acquisition module and correction module can be implemented, as a software executable by the processor.

The coil-coating line is preferably equipped with the gloss management tool to ease the management of the gloss on the coil-coating line.

From a process perspective, the management of the gloss of an organic coating formed by application and curing of a wet film of a radcure paint on a moving strip on the coil-coating line described above is primarily based on the discovery that the temperature of the wet film before UV curing is key. In particular, the inventors have observed that, in dualcure for coil-coating, there can be a relationship between the temperature of the wet film before UV curing and the gloss of the organic coating after EB curing. Consequently, any deviation of the gloss after EB curing can be efficiently and reproducibly corrected by adjusting the power of the heating module and thus the temperature of the wet film before UV curing.

The method is applied on a moving strip. The strip can be one single coil which is unwounded at the entry of the coil-coating line. More generally, the strip is composed of different coils attached to one another end to end. The coils form one essentially continuous strip whose features and technical specifications to be reached at the exit of the coil-coating line vary over time. The strip is moved along the path P of the coil-coating line so that the wet film of radcure paint is applied, preferably heated, and double cured. In particular, the strip is moved along the path P of the coil-coating line so that the wet film of radcure paint is first applied on the strip by the paint applicator, then heated by the heating module, then exposed to UV in the Ultra-Violet curing device and finally cured in the Electron-Beam device. Optionally, the strip can be preheated with an inductor 8 positioned upstream of the paint applicator 2. Optionally, the radcure paint can be heated in the paint applicator.

A first embodiment of the method is described with reference to Figure 2.

The first step 100 of the method for managing the gloss is the setting of some set values needed for a correct regulation.

The set gloss value G_s of the organic coating is first set. This value corresponds to the gloss requested by the customer or by the operator of the coil-coating line. From a practical point of view, it can be manually entered in the gloss management tool, in particular in the setting module. Alternatively, it can be automatically obtained from the order book of the coil-coating line, in particular from the scheduling tool.

As slight deviations of the gloss along the length of the strip are usually acceptable from a quality perspective, a set gloss range R_s of the gloss of the organic coating is also set. It can be entered as a range as such, with a minimal gloss and a maximal gloss or it can be entered as a standard deviation of the set gloss value G_s. Of course, if for some reason, slight deviations have to be avoided, the set gloss value G_s can be entered as the minimal gloss and the maximal gloss or the standard deviation can be set at zero. From a practical point of view, the set gloss range R_s can be manually entered in the gloss management tool, in particular in the setting module. Alternatively, it can be automatically obtained from the management tool of the coil-coating line or from the order book of the coil-coating line, in particular from the scheduling tool. The set gloss range R_s of the gloss can also be obtained from standards, such as EN10169: 2013.

In a second step 120 of the method for managing the gloss, the measure of the gloss G of the organic coating in the at least a width portion downstream of the Electron-Beam curing device is collected.

Preferably, the measure of the temperature T of the wet film in at least a width portion of the moving strip downstream of the heating module and upstream of the Ultra-Violet curing device is also collected. More preferably, the temperature is measured with a wet film temperature measuring device as described above and the gloss is measured with a gloss measuring device as described above.

Preferably, the measure is done at time intervals short enough to have a proper management of the gloss. Examples of time intervals are less than 30s, less than 20s, less than every 10s, less than every 5s, less than every 2s, less than every second. More preferably, the measure is substantially continuous or continuous. Preferably, the measures is collected at time intervals short enough to have a proper management of the gloss. Examples of time intervals are less than every 10s, less than every 5s, less than every 2s, less than every second. More preferably, the measure is collected substantially continuously or continuously. Preferably, the measurements are collected in the gloss management tool, in particular in the acquisition module, more preferably automatically with the appropriate interface.

By “width portion”, it is meant that the moving strip is conceptually divided in portions adjacent to one another in the strip width. There can be one single width portion or a plurality. Consequently, the wet film and the organic coating can also be conceptually divided in the same width portions. By “at least a width portion”, it is meant that the method is implemented either on one width portion or on a plurality of width portions or on the full width of the moving strip. In the case where it is not implemented on the full width, it is thus possible to measure and collect:

- the gloss G of the organic coating in one single width portion if the measure in this width portion is considered relevant enough to manage the gloss of the whole strip width or,
- the glosses of the organic coating in a plurality of width portions so that the gloss in each width portion can be managed independently of the other portions.

Similarly, it is optionally possible to measure and collect:

- the temperature T of the wet film in one single width portion if the measure in this width portion is considered representative enough of the mean temperature over the whole strip width or,
- the temperatures of the wet film in a plurality of width portions so that the temperature in each width portion can be adjusted independently of the other portions

In one variant, the collecting step is performed after the setting step.

In another variant, in particular during a continuous operation of the coil-coating line, the collecting step can be done in parallel to the setting step. In such case of continuous operation, as the strip is composed of different coils attached to one another end to end, changes in the features of the strip and changes in the technical specifications of the strip often happen. While the collecting step is in progress, any one of the set parameters, in particular any one of the set gloss value G_s and/or the set gloss range R_s, may have to be modified for some reason, like a change of specified gloss or a change in radcure paint. Consequently, the setting step is performed.

Preferably, in this second step 120 of the method for managing the gloss, the power PW of the heating module is also collected.

In a third step 130 of the method for managing the gloss, a possible deviation of the measured gloss G beyond the set gloss range R_S is corrected. At first, a possible deviation of the gloss is assessed by comparing the measured gloss G to the set gloss value G_S and/or to the set gloss range R_S. If the measured gloss G is still within the set gloss range R_S, the settings are maintained. If the measured gloss G has deviated beyond the set gloss range R_S, the correction C_P to be applied to the power of the heating module is calculated, taking into account G_S and the measured gloss G, with a closed-loop controller.

The assessment of the gloss deviation can be done at any time. Preferably, it is done at time intervals short enough to have a proper management of the gloss. Examples of time intervals are less than 30s, less than 20s, less than every 10s, less than every 5s, less than every 2s, less than every second. More preferably, the assessment is substantially continuous or continuous.

The calculation of the correction C_P to be applied to the power of the heating module is done with a closed-loop controller. Preferably this controller is a proportional integral derivative controller. As, in some cases, only one or two terms of the controller can provide appropriate control, some parameters of the controller can be set to zero to inactivate some terms. In particular, at least one of the integral term and the derivative term of the proportional integral derivative controller is active. By “active”, it is meant that the term is not set to zero / that it is used for the calculation. In other words, the proportional integral derivative controller is preferably a PI controller, a PD controller, an I controller, a D controller or a PID controller.

Accordingly, it can notably calculate the correction C_P according to an equation of general formula:

$$C_P(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt}$$

or

$$C_P(t) = K_p \left(e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{de(t)}{dt} \right)$$

where e is the error, i.e. the difference between a desired setpoint and a measured process variable, t is the time or instantaneous time and τ is the variable of integration. Other control functions are well known from the person skilled in the art and can be used for controlling the gloss of the organic coating.

In a first variant of the calculation of the correction C_P, the closed-loop control is directly based on the gloss of the organic coating. In other words, the measured process variable is the measured gloss and the desired set point is G_s. In that case, correction C_P is a function of the difference between G_s and the measured gloss G.

In particular, the correction C_P to be applied to the power of the heating module can be calculated according to equation 1:

$$C_P(t) = K_p e_1(t) + K_i \int_0^t e_1(\tau)d\tau + K_d \frac{de_1(t)}{dt} \qquad (1)$$

where K_p is the proportional gain, K_i is the integral gain, K_d is the derivative gain and e_1 is the difference between G_s and the measured gloss G.

In particular, $K_i > 0$ and/or $K_d > 0$.

The good practice rules for the initial selections of K_p, K_i and K_d and their tuning is well known from the person skilled in the art. K_p, K_i and K_d can thus be easily selected and tuned as needed. The initial gains K_p, K_i and K_d can be manually entered in the gloss management tool, in particular in the setting module. They can be set during the setting step.

Alternatively, the correction C_P to be applied to the power of the heating module can be calculated according to the following equation:

$$C_P(t) = K_p \left(e_1(t) + \frac{1}{T_i} \int_0^t e_1(\tau)d\tau + T_d \frac{de_1(t)}{dt} \right)$$

where K_p is the proportional gain, T_i is the integration time, T_d is the derivative time and e_1 is the difference between G_s and the measured gloss G.

In particular $1 / T_i > 0$.and/or $T_d > 0$.

The good practice rules for the initial selections of K_p, T_i and T_d and their tuning is well known from the person skilled in the art. K_p, T_i and T_d can thus be easily selected and tuned as needed. The initial terms K_p, T_i and T_d can be manually entered in the gloss management tool, in particular in the setting module. They can be set during the setting step.

In a second variant, where the collecting step further comprises collecting the measure of the temperature T of the wet film in at least a width portion of the moving strip downstream of the heating module and upstream of the Ultra-Violet curing device, as it has been observed that there is a relationship between the temperature of the wet film before UV curing and the gloss of the organic coating after EB curing, the closed-loop control on the power of the heating module is based on the temperature of the wet film in the at least a width portion downstream of the heating module and upstream of the UV curing device. In other words, the measured process variable is the measured temperature and the desired set point is the corrected temperature T_c to be reached by the wet film, in the at least a width portion downstream of the heating module and upstream of the UV curing device, to obtain the set gloss value G_s.

Accordingly, in a first sub-step of the correcting step, the corrected temperature T_c to be reached by the wet film in the at least a width portion downstream of the heating module and upstream of the UV curing device is calculated.

Generally speaking, the corrected temperature T_c is calculated according to equation 2:

$$T_c = f_1 (T, G, G_s) \qquad (2)$$

where function f_1 of a predefined mathematical relation between the temperature of the wet film before Ultra-Violet curing and the gloss of the organic coating after Electron-Beam curing. By “predefined”, it is meant that a calibration step, preferably as described below, has been performed before implementing the method on the coil-coating line.

The function f_1 can be obtained in a calibration step performed ahead of the setting step. During this calibration step, wet films of the radcure paint to be used on the coil-coating line are heated at different temperatures, cured by dualcure in standard curing conditions and the gloss of the organic coatings is measured. The function f_1 can thus be deducted. This calibration step can be done once and for all and does not have to be performed each time the method according to the invention is implemented. The function f_1 can be manually entered in the gloss management tool, in particular in the setting module. Alternatively, it can be automatically obtained by crossing the predefined mathematical relations entered in the gloss management tool, possibly in the form of a table, with the paint reference from the order book of the coil-coating line, in particular from the scheduling tool. The function f_1 can be set during the setting step.

In particular, it has been observed that for some radcure paints commercially available for coil-coating of steel, there is a linear mathematical relation between the temperature of the wet film before Ultra-Violet curing and the gloss of the organic coating after Electron-Beam curing, as expressed by the following equation:

$$T = T_0 - K\,G$$

Where K is the proportionality constant.

In that case, the corrected temperature T_c is calculated according to equation 3:

$$T_c = T + K\,(G - G_s) \qquad (3)$$

The proportionality constant K can be obtained in a calibration step performed ahead of the setting step. During this calibration step, wet films of the radcure paint to be used on the coil-coating line are heated at different temperatures, cured by dualcure in standard curing conditions and the gloss of the organic coatings is measured. The proportionality constant K can thus be deducted. It is preferably expressed in °C/GU, °F/GU or K/GU, depending on the temperature unit. This calibration step can be done once and for all and does not have to be performed each time the method according to the invention is implemented.

From a practical point of view, during the correcting step, the proportionality constant K is obtained from a predefined linear mathematical relation between the temperature of the wet film before Ultra-Violet curing and the gloss of the organic coating after Electron-Beam curing, the predefined linear mathematical relation being available to the operator of the coil-coating line. By “predefined”, it is meant that a calibration step, preferably as described above, has been performed before implementing the method on the coil-coating line. The proportionality constant K can be manually entered in the gloss management tool, in particular in the setting module. Alternatively, it can be automatically obtained by crossing the predefined linear mathematical relations entered in the gloss management tool, possibly in the form of a table, with the paint reference from the order book of the coil-coating line, in particular from the scheduling tool.

For example, it has been observed that for some radcure paints commercially available for coil-coating of steel, K is usually comprised between 0.3 and 1.2. More generally, $K > 0$.

Once the corrected temperature T_c has been calculated, the correction C_P to be applied to the power of the heating module is calculated as a function of the difference between T_c and the measured temperature T.

In particular, in the case of a proportional integral derivative controller in the parallel form, the correction C_P can be calculated according to equation 4:

$$C_P(t) = K'_p e_2(t) + K'_i \int_0^t e_2(\tau)d\tau + K'_d \frac{de_2(t)}{dt} \quad (4)$$

where K'_p is the proportional gain, K'_i is the integral gain, K'_d is the derivative gain and e_2 is the difference between T_c and the measured temperature T.

In particular, $K'_i > 0$ and/or $K'_d > 0$.

The good practice rules for the initial selections of K'_p, K'_i and K'_d and their tuning is well known from the person skilled in the art. K'_p, K'_i and K'_d can thus be easily selected and tuned as needed. The initial gains K'_p, K'_i and K'_d can be manually entered in the gloss management tool, in particular in the setting module. They can be set during the setting step.

Alternatively, in the case of a proportional integral derivative controller in the standard form, the correction C_P to be applied to the power of the heating module can be calculated according to the following equation:

$$C_P(t) = K'_p \left(e_2(t) + \frac{1}{T'_i} \int_0^t e_2(\tau)d\tau + T'_d \frac{de_2(t)}{dt} \right)$$

where K'_p is the proportional gain, T'_i is the integration time, T'_d is the derivative time and e_2 is the difference between T_c and the measured temperature T.

In particular $1 / T'_i > 0$ and/or $T'_d > 0$.

The good practice rules for the initial selections of K'_p, T'_i and T'_d and their tuning is well known from the person skilled in the art. K'_p, T'_i and T'_d can thus be easily selected and tuned as needed. The initial terms K'_p, T'_i and T'_d can be manually entered in the gloss management tool, in particular in the setting module. They can be set during the setting step.

This second variant of the calculation of the correction C_P is very convenient to avoid the juxtaposition of interdependent closed-loop controls and to control that the temperature of the wet film does not exceed a maximum temperature T_{max} that would degrade the radcure paint, as will be described in detail later on.

Once the correction C_P to be applied to the power of the heating module has been calculated, a line setting is adjusted taking into account the correction C_P, so that the deviation of the measured gloss is corrected.

In particular, once the correction C_p has been calculated, the power of the heating module is adjusted by the correction C_p. Adjusting the power of the heating module includes turning the heating module on or off. Thanks to the adjustment of the heating module, the temperature of the wet film in the width portion downstream of the heating module and upstream of the Ultra-Violet curing device is corrected and gloss of value G_s is obtained on the organic coating in the width portion downstream of the Electron-Beam curing device. The adjustment of the power of the heating module can be done either manually by an operator or automatically with the help of the gloss management tool, in particular of the correction module.

Alternatively, in the case where the coil-coating line is equipped with an inductor upstream of the paint applicator, once the correction C_p has been calculated, the power of the inductor is adjusted so that the temperature of the strip at the level of the paint applicator is adjusted so that the gloss of value G_s is obtained on the organic coating in the at least a width portion of the moving stream downstream of the Electron-Beam curing device. if the corrected temperature T_c has been calculated before calculating the correction C_p, the power of the inductor is adjusted so that the wet film reaches the corrected temperature Tc in the at least a width portion of the moving strip downstream of the cooling module / heating module and upstream of the Ultra-Violet curing device. This alternative way of correcting the gloss is helpful notably in the case where the heating module is already at maximum capacity and the temperature of the wet film upstream of the Ultra-Violet curing device has to be further increased. By further heating the strip in the inductor, the overheating to be provided by the heating module is decreased.

In one variant, the correcting step 130 is performed after the collecting step 120.

In another variant, in particular during a continuous operation of the coil-coating line, the correcting step can be done in parallel to the collecting step. In such case of continuous operation, as the strip is composed of different coils attached to one another end to end, changes in the features of the strip and changes in the technical specifications of the strip often happen. They can make the gloss deviate.

While the collecting step is in progress, the correcting step is performed to correct the measured gloss.

Optionally, the method further comprises a step 110 during which initial line conditions are set. This step is referred to as the initial line setting step. As explained above, the method is such that any deviation of the measured gloss beyond the set gloss range R_s is corrected. That said, at the start of a production campaign on the coil-coating line or after an important change in, for example, the strip format, the paint thickness, the paint color or the line speed, the line conditions might be shifted from the line conditions appropriate for reaching the set gloss value G_s. In such case, the heating module may not heat appropriately and/or may need some time to reach the power corresponding to the correction C_T and/or may not be powerful enough to allow the wet film to reach the corrected temperature T_c. Consequently, a portion of the coated strip may have to be scrapped because the gloss is out of the specifications. Moreover, the UV dose to which the wet film must be exposed to initiate the surface roughness that will bring the set gloss value may not be appropriate. In such case, the heating module needs to compensate for the shifted UV dose, possibly by heating strongly, which takes time. Here again, a portion of the coated strip may have to be scrapped because the gloss is out of the specifications. In order to minimize the length of coated strip out of specifications, it is advantageous to set initial line conditions.

To do so, in a first sub-step, a plurality of process parameters and/or of specifications of the coated strip are collected. An example of process parameters is the initial line speed LS_0. It is preferably the one recommended for the next coil to be coated on the coil-coating line. Another example is the initial thickness FTh_0 of the wet film applied on the strip by the paint applicator. The initial film thickness is preferably the one that corresponds to the organic coating thickness specified for the next coil to be coated on the coil-coating line. Another example is the temperature of the moving strip before the paint applicator, preferably before the inductor. Examples of specifications are the initial strip thickness STh_0, the initial strip width SWd_0, the paint color. Preferably, the initial line speed LS_0, initial thickness FTh_0, the initial strip thickness STh_0, the initial strip width SWd_0 and the paint color are collected. From a practical point of view, process parameters and/or specifications can be manually entered in the gloss management tool, in particular in the setting module. Alternatively, they can be automatically obtained from the order book of the coil-coating line, in particular from the scheduling tool and/or deducted from the order book. For example, the initial film thickness FTh_0 can be deducted from the organic coating thickness specified in the order book.

Once process parameters and/or specifications have been collected, in a second sub-step, the initial line conditions are set taking into account the process parameters and/or specifications that have been collected. In particular, they are calculated from the process parameters and/or specifications that have been collected. The following initial line conditions can be set:

- the initial power PW_0 of the heating module,
- the initial UV dose D_0 of the Ultra-Violet curing device, or of the UV module if applicable,
- the initial length L_0 between the Ultra-Violet curing device, or the UV module if applicable, and the Electron-Beam curing device.

The initial power PW_0 can be set knowing the mass flow of the moving strip, the specific heat capacity of the strip and the heating yield. The initial UV dose D_0 can set based on data obtained in a calibration step performed ahead of the initial line setting step. The initial length L_0 can be set based on data obtained in a calibration step performed ahead of the initial line setting step.

From a practical point of view, the initial line conditions can be manually entered in the management tool of the coil-coating line. Alternatively, they can be automatically injected by the gloss management tool in the management tool of the coil-coating line.

In one variant, the initial line setting step 110 is performed before the setting step 100. It helps starting the production with line conditions that are already optimized for the first coil of the production campaign, in addition to an initial combination of set gloss value G_s and set gloss range R_s. During production, the collecting step and the correcting step can be performed to manage the gloss. When any one of the set parameters, in particular any one of the set gloss value G_s and/or the set gloss range R_s, has to be modified for some reason, like a change of specified gloss or a change in radcure paint, then it is relied on the performance of the collecting step 120 and the correcting step 130 to keep the measured gloss within the set gloss range R_s.

In another variant, the initial line setting step 110 is performed after the setting step 100, as illustrated on Figure 2. This way the setting of the initial line conditions can be done by taking the set gloss value G_s into account. The line conditions are thus better optimized for the first coil of the production campaign. Moreover, during production, when any one of the set parameters, in particular any one of the set gloss value G_s and/or the set gloss range R_s has to be modified for some reason, the initial line settings can be reset to help minimizing the transitional period.

In another variant, the initial line setting step 110 is performed before and after the setting step 100 to take advantages of both variants described above.

In another variant, in particular during a continuous operation of the coil-coating line, the initial line setting step can be done in parallel to the collecting step. In such case of continuous operation, as the strip is composed of different coils attached to one another end to end, changes in the features of the strip and changes in the technical specifications of the strip often happen. Re-initializing the line conditions when one of these changes occurs helps to reach the set gloss value as fast as possible.

A second embodiment of the method is now described with reference to Figure 3.

This embodiment mainly differs from the first one in that the correcting step comprises additional sub-steps to:

- ensure that the temperature of the wet film upstream of the UV curing device does not exceed a maximum temperature T_{max} that would degrade the radcure paint and,
- correct the deviation of the measured gloss G accordingly.

Thanks to this configuration, the method further prevents the thermal degradation of the wet film when heated in the heating module.

The details provided when describing the first embodiment apply for the second embodiment. The additional steps and corresponding features are described in detail now.

The setting step 100 further comprises setting a maximum temperature T_{max} for the radcure paint. This temperature can be the one recommended by the paint supplier. It can alternatively be identified by the operator of the coil-coating line, notably by measuring emanations of paint monomers as a function of the temperature, this measure being done off line or possibly on line at the level of the heating module. From a practical point of view, the maximum temperature T_{max} can be manually entered in the gloss management tool, in particular in the setting module. Alternatively, it can be automatically obtained by crossing the different maximum temperatures entered in the gloss management tool with the paint reference from the order book of the coil-coating line, in particular from the scheduling tool.

The collecting step 120 comprises collecting the measure of the temperature T of the wet film in at least a width portion of the moving strip downstream of the heating module and upstream of the Ultra-Violet curing device.

The collecting step 120 further comprises collecting the UV dose D of the UV module. The power of the UV module is generally known from the operator, possibly from the management tool of the coil-coating line, but, for a given power, the actual UV dose to which the wet film is exposed varies with the line speed LS. Accordingly, the UV dose is calculated based on the power of the UV module and the line speed and collected. The line speed itself is generally known from the operator, possibly from the management tool of the coil-coating line.

Preferably the UV dose is re-calculated and collected each time either the power of the UV module and/or the line speed is adjusted. More preferably, the collection of the UV dose is substantially continuous. Preferably, the UV dose is collected in the gloss management tool, in particular in the acquisition module, more preferably automatically with the appropriate interface.

During the correcting step 130, if the corrected temperature T_c has been calculated before calculating the correction C_p, it is compared to the maximum temperature T_{max}. Otherwise, the correcting step can comprise a sub-step of calculating the corrected temperature T_c to be reached by the wet film, in the at least a width portion downstream of the heating module and upstream of the Ultra-Violet curing device. This sub-step can be done after calculating the correction C_p or at any other appropriate time. Once this sub-step has been done, T_c can be compared to the maximum temperature T_{max}. Alternatively, T can be compared to the maximum temperature T_{max}.

If T_c (or T) is inferior to T_{max}, then the power of the heating module is adjusted by the correction C_p, as detailed in the first embodiment.

If T_c (or T) is superior to T_{max}, then the gloss has to be corrected without increasing the power of the heating module any further. One way to do so is to adjust, in particular to increase, the power of the UV module. It has indeed been observed that it impacts the gloss of the organic coating. The more the UV dose on the wet film increases, the more the gloss decreases. Consequently, the correcting step 130 further comprises calculating the correction C_D to be applied to the UV dose to which the wet film in the at least a width portion of the moving strip must be exposed in the UV module according to equation 5:

$$C_D = f_2 (G, G_s) \qquad (5)$$

Equation (5) can be obtained in a calibration step performed ahead of the correcting step, preferably ahead of the setting step. During this calibration step, wet films of the radcure paint to be used on the coil-coating line are exposed to different UV doses, cured by EB in standard curing conditions and the gloss of the organic coating is measured. Function f_2 can thus be deducted for each radcure paint. This calibration step can be done once and for all and does not have to be performed each time the method according to the invention is implemented. Alternatively, function f_2 can be a PID function of the difference between G_s and the measure gloss G.

Preferably, function f_2 of the predefined mathematical relation between the UV dose to which the wet film of radcure paint is exposed and the gloss of the organic coating after Electron-Beam curing is set during the setting step. By “predefined”, it is meant that a calibration step, preferably as described above, has been performed before implementing the method on the coil-coating line. The function f_2 can be manually entered in the gloss management tool, in particular in the setting module. Alternatively, it can be automatically obtained by crossing the predefined mathematical relations entered in the gloss management tool with the paint reference from the order book of the coil-coating line, in particular from the scheduling tool.

For example, it has been observed that for radcure paints commercially available for coil-coating of steel, f_2 is usually related to a gloss curve decreasing towards an asymptote as the UV dose increases.

Once the correction C_D to be applied to the UV dose has been calculated, a line setting other than the power of the heating module, and other than the power of the inductor if applicable, is adjusted taking into account the calculated correction C_D, so that the deviation of the measured gloss is corrected.

In the variant illustrated on Figure 3, once the correction C_D to be applied to the UV dose has been calculated, the power of the UV module is adjusted, in particular increased, so that the wet film in the at least a width portion of the moving strip is exposed to the UV dose $D_c = D + C_D$ in the UV module. Thanks to the adjustment of the UV module, the UV dose to which the wet film is exposed in the width portion in the UV module is corrected and gloss of value Gs is obtained on the organic coating in the width portion downstream of the Electron-Beam curing device. The adjustment of the power of the UV module can be done either manually by an operator or automatically with the help of the gloss management tool.

A third embodiment of the method is now described with reference to Figure 4.

This embodiment mainly differs from the second one in that the correcting step comprises additional sub-steps to:

- ensure that the UV dose does not exceed a maximum UV dose D_{max} to which the wet film can be exposed,
- correct the deviation of the measured gloss G accordingly.

Thanks to this configuration, the method further prevents the overcuring of the wet film in the UV curing device, which might impact detrimentally the gloss.

The details provided when describing the first and second embodiments apply for the third embodiment. The additional steps and corresponding features are described in detail now.

In this embodiment, the UV module of the Ultra-Violet curing device of the coil-coating line is movable along the path P. Accordingly the length L between the UV module and the Electron-Beam curing device can be adjusted.

The setting step 100 further comprises setting a maximum UV dose D_{max} to which the wet film can be exposed in the UV module. This UV dose can be the one recommended by the paint supplier. It can alternatively be identified by the operator of the coil-coating line notably during a calibration step. From a practical point of view, the maximum UV dose D_{max} can be manually entered in the gloss management tool, in particular in the setting module. Alternatively, it can be automatically obtained by crossing the different maximum UV doses entered in the gloss management tool with the paint reference from the order book of the coil-coating line, in particular from the scheduling tool.

The collecting step 120 further comprises collecting the length L between the UV module and the Electron-Beam curing device. This length is generally known from the operator, possibly from the management tool of the coil-coating line. It can be collected manually. Preferably it is collected in the gloss management tool, more preferably automatically with the appropriate interface. Preferably, it is collected only when the length L is modified.

During the correcting step 130, once the correction C_D to be applied to the UV dose has been calculated, the sum D + C_D (referred to below as D_c) is compared to the maximum UV dose D_{max}. If D_c is inferior to D_{max}, then the power/setting of the UV module is adjusted so that the wet film in the at least a width portion of the moving strip is exposed to the UV dose D_c in the UV module. Thanks to the adjustment of the UV module, the UV dose to which the wet film is exposed in the width portion in the UV module is corrected and a gloss of value Gs is obtained on the organic coating in the width portion downstream of the Electron-Beam curing device, as in the second embodiment.

If D_c is superior to D_{max}, then the gloss has to be corrected without increasing the UV dose of the UV module any further. One way to do so is to adjust, in particular to extend, the length between the UV module and the Electron-Beam curing device. It has indeed been observed that it impacts the gloss of the organic coating. The longer the time between the UV curing and the EB curing, the lower the gloss. Consequently, the correcting step 130 further comprises calculating the correction C_L to be applied to the length L between the UV module and the Electron-Beam curing device according to equation 6:

$$C_L = f_3\ (G, G_s) \qquad (6)$$

Equation (6) can be obtained in a calibration step performed ahead of the correcting step, preferably ahead of the setting step. During this calibration step, wet films of the radcure paint to be used on the coil-coating line are exposed sequentially to UV curing and EB curing in standard curing conditions with varying time between the two curings and the gloss of the organic coating is measured. Function f_3 can thus be deducted for each radcure paint. This calibration step can be done once and for all and does not have to be performed each time the method according to the invention is implemented. Alternatively, function f_3 can be a PID function of the difference between G_s and the measure gloss G.

Preferably, function f_3 of the predefined mathematical relation between the length between the UV module and the Electron-Beam curing device and the gloss of the organic coating after Electron-Beam curing is set during the setting step. By “predefined”, it is meant that a calibration step, preferably as described above, has been performed before implementing the method on the coil-coating line. The function f_3 can be manually entered in the gloss management tool, in particular in the setting module. Alternatively, it can be automatically obtained by crossing the predefined mathematical relations entered in the gloss management tool with the paint reference from the order book of the coil-coating line, in particular from the scheduling tool.

For example, it has been observed that for radcure paints commercially available for coil-coating of steel, f_3 is usually related to a gloss curve decreasing towards an asymptote as L increases.

Once the correction C_L to be applied to the length between the UV module and the Electron-Beam curing device has been calculated, a line setting other than the power of the heating module, and other than the power of the inductor if applicable, and other than the power of the UV module is adjusted taking into account the calculated correction C_L, so that the deviation of the measured gloss is corrected.

In the variant illustrated on Figure 4, once the correction C_L has been calculated, the length between the UV module and the Electron-Beam curing device is adjusted, in particular extended, to the corrected length $L_c = L + C_L$ so that the gloss of value G_s is obtained on the organic coating in the at least a width portion of the moving strip downstream of the Electron-Beam curing device. The adjustment of the length can be done either manually by an operator or automatically with the help of the gloss management tool.

Alternatively, notably if the length between the UV module and the Electron-Beam curing device cannot be further extended or shortened, the line speed can be adjusted. In that case, the initial line setting can be performed again to adjust to the new line speed, the initial power PW_0 of the heating module, the initial UV dose D_0 of the Ultra-Violet curing device and the initial length L_0 between the Ultra-Violet curing device and the Electron-Beam curing device.

The invention also relates to a method for forming an organic coating on a moving strip on a coil-coating line comprising, sequentially along the path P of the moving strip, a paint applicator, a heating device comprising a heating module, an Ultra-Violet curing device and an Electron-Beam curing device, the method comprising the steps of:

- applying a wet film of a radcure paint on the moving strip with the paint applicator,
- heating the wet film of radcure paint in the heating module,
- exposing the wet film of radcure paint to UV in the Ultra-Violet curing device,
- curing the wet film of radcure paint in the Electron-Beam device to form the organic coating,

the gloss of the organic coating being managed by:

- Setting a set gloss value G_S of the organic coating and a set gloss range R_S of the gloss of the organic coating,
- Collecting the measure of the gloss G of the organic coating in the at least a width portion downstream of the Electron-Beam curing device,
- Correcting a deviation of the measured gloss G beyond the set gloss range R_S, this correcting step comprising a sub-step of calculating the correction C_P to be applied to the power of the heating module, taking into account G_S and the measured gloss G, with a closed-loop controller and a sub-step of adjusting a setting of the coil-coating line taking into account the calculated correction C_P.

All the details provided in relation to the method for managing the gloss and all the details provided in relation to the coil-coating line apply to the method for forming the organic coating.

The invention also relates to a method for manufacturing a prepainted metal, comprising a metal strip and an organic coating, on a coil-coating line comprising, sequentially along the path P of the moving metal strip, a paint applicator, a heating device comprising a heating module, an Ultra-Violet curing device and an Electron-Beam curing device, the method comprising the steps of:

- applying a wet film of a radcure paint on the moving metal strip with the paint applicator,
- heating the wet film of radcure paint in the heating module,
- exposing the wet film of radcure paint to UV in the Ultra-Violet curing device,
- curing the wet film of radcure paint in the Electron-Beam device to form the organic coating,

the gloss of the organic coating being managed by:

- Setting a set gloss value G_s of the organic coating and a set gloss range R_s of the gloss of the organic coating,
- Collecting the measure of the gloss G of the organic coating in the at least a width portion downstream of the Electron-Beam curing device,
- Correcting a deviation of the measured gloss G beyond the set gloss range R_s, this correcting step comprising a sub-step of calculating the correction C_P to be applied to the power of the heating module, taking into account G_s and the measured gloss G, with a closed-loop controller and a sub-step of adjusting a setting of the coil-coating line taking into account the calculated correction C_P.

All the details provided in relation to the method for managing the gloss and all the details provided in relation to the coil-coating line apply to the method for manufacturing the prepainted metal.

CLAIMS

1) Method for managing the gloss of an organic coating formed by application and curing of a wet film of a radcure paint on a moving strip on a coil-coating line comprising, sequentially along the path P of the moving strip, a paint applicator, a heating device comprising heating module, an Ultra-Violet curing device and an Electron-Beam curing device, the method comprising the steps of:
   - Setting a set gloss value G_S of the organic coating and a set gloss range R_S of the gloss of the organic coating,
   - Collecting the measure of the gloss G of the organic coating in the at least a width portion downstream of the Electron-Beam curing device,
   - Correcting a deviation of the measured gloss G beyond the set gloss range R_S, this correcting step comprising a sub-step of calculating the correction C_P to be applied to the power of the heating module, taking into account G_S and the measured gloss G, with a closed-loop controller and a sub-step of adjusting a setting of the coil-coating line taking into account the calculated correction C_P.

2) Method according to claim 1 wherein the closed-loop controller is a proportional integral derivative controller.

3) Method according to any one of claims 1 or 2 wherein the correction C_P is a function of the difference between G_S and the measured gloss G.

4) Method according to any one of claims 1 to 3 wherein the correction C_P to be applied to the power of the heating module is calculated according to equation 1:

$$C_P(t) = K_p e_1(t) + K_i \int_0^t e_1(\tau) d\tau + K_d \frac{de_1(t)}{dt} \qquad (1)$$

where K_p is the proportional gain, K_i is the integral gain, K_d is the derivative gain and e_1 is the difference between G_S and the measured gloss G.

5) Method according to any one of claims 1 or 2 wherein the collecting step further comprises collecting the measure of the temperature T of the wet film in at least a width portion of the moving strip downstream of the heating module and upstream of the Ultra-Violet curing device and wherein the correcting step further comprises a sub-step of calculating the corrected temperature T_c to be reached by the wet film, in the at least a width portion downstream of the heating module and upstream of the Ultra-Violet curing device.

6) Method according to claim 5 wherein the corrected temperature T_c is calculated according to equation 2:

$$T_c = f_1 (T, G, G_s) \qquad (2)$$

where function f_1 of a predefined mathematical relation between the temperature of the wet film before Ultra-Violet curing and the gloss of the organic coating after Electron-Beam curing.

7) Method according to claim 5 wherein the corrected temperature T_c is calculated according to equation 3:

$$T_c = T + K (G – G_s) \qquad (3)$$

8) Method according to any one of claims 5 to 7 wherein the correction C_P is a function of the difference between T_c and the measured temperature T.

9) Method according to any one of claims 5 to 7 wherein the correction C_P to be applied to the power of the heating module is calculated according to equation 4:

$$C_P(t) = K'_p e_2(t) + K'_i \int_0^t e_2(\tau) d\tau + K'_d \frac{de_2(t)}{dt} \qquad (4)$$

where K'_p is the proportional gain, K'_i is the integral gain, K'_d is the derivative gain and e_2 is the difference between T_c and the measured temperature T.

10) Method according to any one of claims 1 to 9 wherein the sub-step of adjusting a setting of the coil-coating line comprises adjusting the power of the heating module by the correction C_P.

11) Method according to any one of claims 5 to 9 wherein:

- the Ultra-Violet curing device comprises a UV module,
- the setting step further comprises setting a maximum temperature T_{max} for the radcure paint,
- the collecting step further comprises collecting the UV dose D of the UV module,
- the sub-step of adjusting a setting of the coil-coating line comprises:
    - Evaluating if T_c is superior to T_{max},
    - If not, adjusting the power of the heating module by the correction C_p,
    - If T_c is superior to T_{max}:
        - calculating the correction C_D to be applied to the UV dose to which the wet film in the at least a width portion must be exposed in the UV module according to equation 5:

$$C_D = f_2 (G, G_s) \qquad (5)$$

        - adjusting a setting of the coil-coating line other than the power of the heating module, taking into account the calculated correction C_D.

12) Method according to claim 11 wherein the sub-step of adjusting a setting of the coil-coating line other than the power of the heating module comprises adjusting the power of the UV module so that the wet film in the at least a width portion of the moving strip is exposed to the corrected UV dose $D_c = D + C_D$.

13) Method according to claim 11 wherein:

- the UV module is movable along the path P,
- the setting step further comprises setting a maximum UV dose D_{max} to which the wet film can be exposed in the UV module,
- the collecting step further comprises collecting the length L between the UV module and the Electron-Beam curing device,

- the sub-step of adjusting a setting of the coil-coating line other than the power of the heating module comprises:
  - Evaluating if $D + C_D$ is superior to D_{max},
  - If not, adjusting the power of the UV module so that the wet film in the at least a width portion of the moving strip is exposed with the corrected UV dose $D_c = D + C_D$,
  - If $D + C_D$ is superior to D_{max}:
    - calculating the correction C_L to be applied to the length between the UV module and the Electron-Beam curing device according to equation 6:

$$C_L = f_3 (G, G_s) \qquad (6)$$

    - adjusting a setting of the coil-coating line other than the power of the heating module and than the power of the UV module, taking into account the calculated correction C_L.

14) Method according to claim 13 wherein the sub-step of adjusting a setting of the coil-coating line other than the power of the heating module and than the power of the UV module comprises adjusting the length between the UV module and the Electron-Beam curing device to the corrected length $L_c = L + C_L$ so that the gloss of value G_s is obtained on the organic coating in the at least a width portion of the moving strip downstream of the Electron-Beam curing device.

15) Coil-coating line comprising sequentially a paint applicator, a heating device comprising a heating module, an Ultra-Violet curing device and an Electron-Beam curing device, the coil-coating line further comprising a gloss management tool for managing the gloss of an organic coating formed by application and curing of a wet film of a radcure paint on a moving strip on the coil-coating line, the gloss management tool comprising:

- a setting module setting a set gloss value G_s of the organic coating and a set gloss range R_s of the gloss of the organic coating,

- an acquisition module collecting the measure of the gloss G of the organic coating in the at least a width portion downstream of the Electron-Beam curing device,
- a correction module correcting a deviation of the measured gloss G beyond the set gloss range R_s, the correction comprising a sub-step of calculating the correction C_P to be applied to the power of the heating module, taking into account G_s and the measured gloss G, with a closed-loop controller and a sub-step of adjusting a setting of the coil-coating line taking into account the calculated correction C_P.

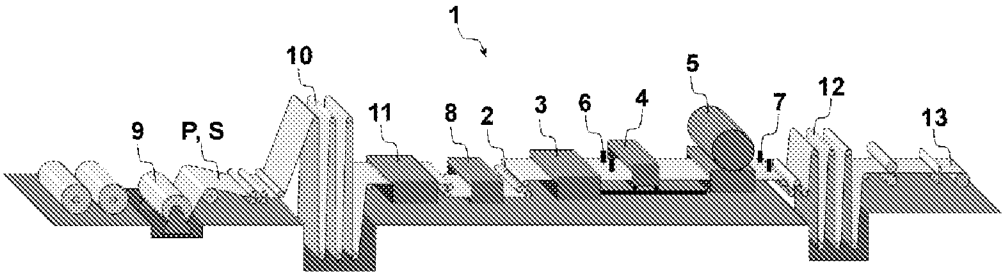
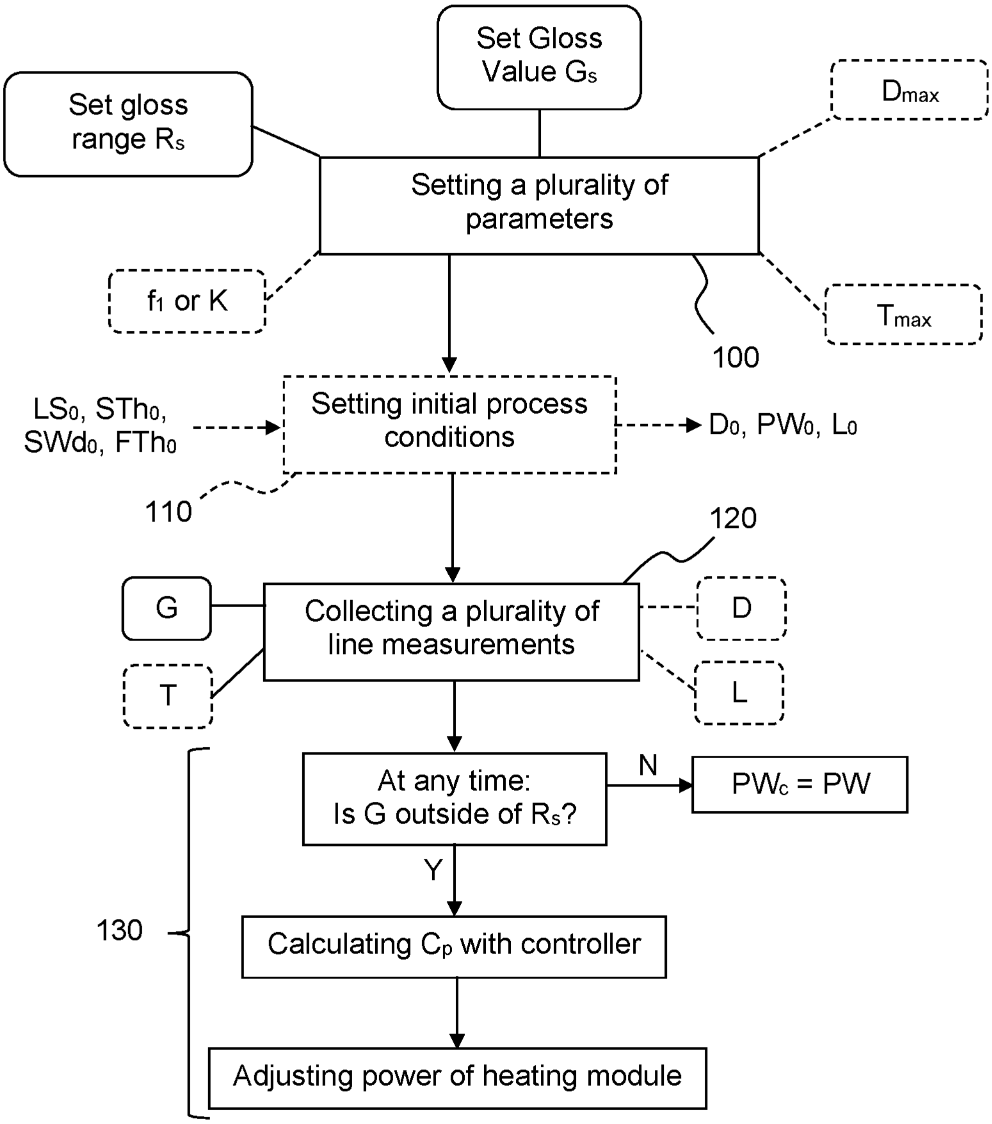


Figure 1



Set Gloss Value Gs
Set gloss range Rs
Dmax
Setting a plurality of parameters
f1 or K
Tmax
100
LS0, STh0, SWd0, FTh0
Setting initial process conditions
D0, PW0, L0
110
120
G
Collecting a plurality of line measurements
D
T
L
At any time: Is G outside of Rs?
N
PWc = PW
Y
130
Calculating Cp with controller
Adjusting power of heating module

Figure 2

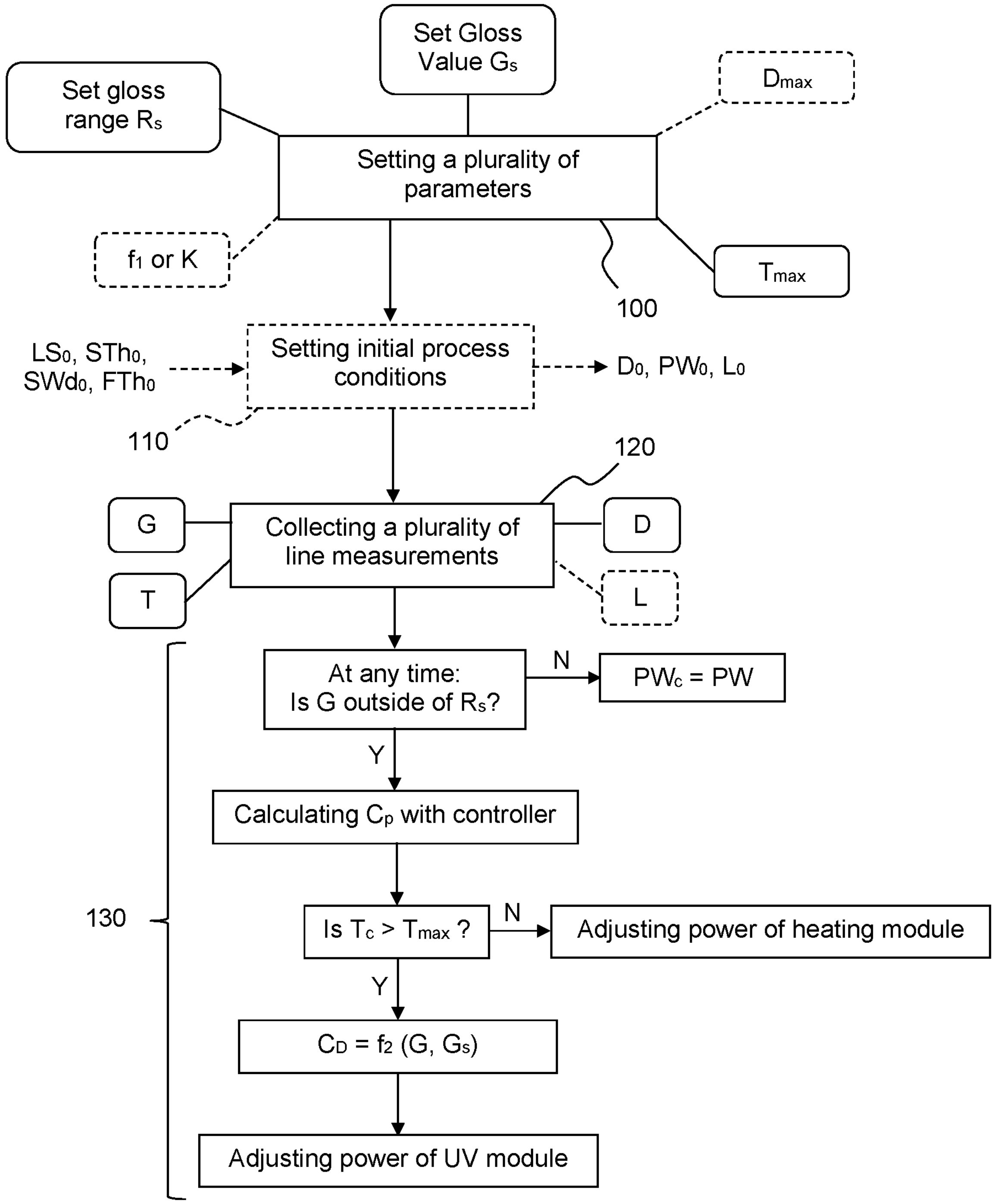
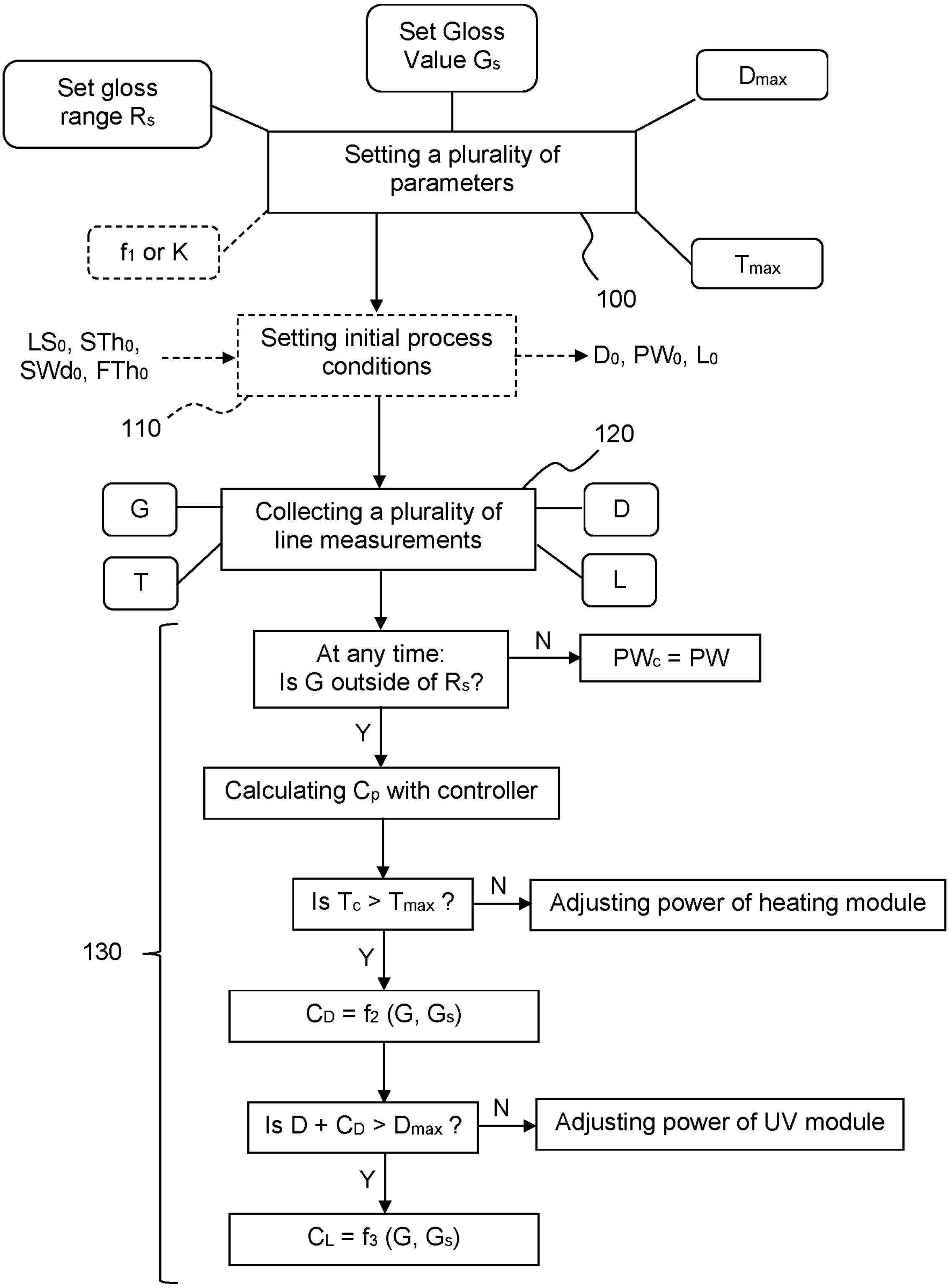

Set Gloss Value G_s
Set gloss range R_s
D_{max}
Setting a plurality of parameters
f_1 or K
T_{max}
100
LS_0, STh_0, SWd_0, FTh_0
Setting initial process conditions
D_0, PW_0, L_0
110
120
G
Collecting a plurality of line measurements
D
T
L
At any time: Is G outside of R_s?
N
PW_c = PW
Y
Calculating C_p with controller
130
Is T_c > T_{max} ?
N
Adjusting power of heating module
Y
C_D = f_2 (G, G_s)
Adjusting power of UV module

Figure 3



Set Gloss Value Gs
Set gloss range Rs
Dmax
Setting a plurality of parameters
f1 or K
Tmax
100
LS0, STh0, SWd0, FTh0
Setting initial process conditions
D0, PW0, L0
110
120
G
Collecting a plurality of line measurements
D
T
L
At any time: Is G outside of Rs?
N
PWc = PW
Y
Calculating Cp with controller
Is Tc > Tmax ?
N
Adjusting power of heating module
130
Y
CD = f2 (G, Gs)
Is D + CD > Dmax ?
N
Adjusting power of UV module
Y
CL = f3 (G, Gs)

Figure 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2023/053544

A. CLASSIFICATION OF SUBJECT MATTER

INV.	B05D3/02	B05D3/06	B05D5/06	B05D7/14	
ADD.	B05D1/26	B05D1/30	B05D1/28	B05D3/04	B05D5/02

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)
B05D

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)

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	EP 2 703 092 A1 (BAYER MATERIALSCIENCE AG [DE]) 5 March 2014 (2014-03-05) paragraph [0001] paragraph [0003] - paragraph [0010] paragraph [0028] paragraph [0063] - paragraph [0066] -----	1-15
X	EP 1 072 325 A2 (ARMSTRONG WORLD IND INC [US]) 31 January 2001 (2001-01-31) paragraph [0001] - paragraph [0002] -----	1-15
X	CN 107 486 380 A (ZHONGSHAN EBC NEW MATERIAL TECH CO LTD) 19 December 2017 (2017-12-19)	15
A	abstract; figures 1,2, 4, 5 -----	1-14
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] 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
16 October 2023	24/10/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Maxisch, Thomas

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 228 813 A2 (ARMSTRONG WORLD IND INC [US]) 7 August 2002 (2002-08-07) paragraph [0001] - paragraph [0007] paragraph [0011] - paragraph [0012] paragraph [0027] paragraph [0038] - paragraph [0041] paragraph [0044] - paragraph [0045] paragraph [0049] - paragraph [0054] paragraph [0075] - paragraph [0077] -----	1-15
X	DE 196 25 548 A1 (SCHLOEMANN SIEMAG AG [DE]) 2 January 1998 (1998-01-02) column 1, line 3 - line 15 column 2, line 43 - column 3, line 40 figure 1 -----	1-15
E	WO 2023/053107 A1 (ARCELORMITTAL [LU]) 6 April 2023 (2023-04-06) the whole document -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2023/053544

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			CA	2313770	A1	28-01-2001
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