United States Patent

Ayers

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[54] METHOD AND MEANS FOR CONVERTING METAL POWDERS TO CONTINUOUS STRIP FORM

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[52] **U.S. Cl.** **264/40,** 264/70, 264/111, 164/154

[51] **Int. Cl.** **B22f 3/18**

[58] **Field of Search** .....264/111, 40, 70; 18/9, 10, 18/11, 2 HA; 25/41 J; 198/107; 164/154

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Assistant Examiner—J. R. Hall
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[57] **ABSTRACT**

The invention is directed to a new method for converting powdered metals to strip form on a continuous basis, which is productive of commercially acceptable levels of strip uniformity in respect of such characteristics as strip thickness, density, edge conditions, metallurgical characteristics, etc. The invention is especially applicable to, although by no means limited to, the processing into continuous strip form of water-atomized ferrous powders. In the new process, metal powder is controllably fed over a generally horizontal delivery surface in a strip-like layer. The feeding facility is an asymmetrically vibrating unit which advances the strip-like powder layer in the feeding direction while simultaneously vibrating it. During the vibratory feeding step, the powder is consolidated, and gases are dispelled from the powder layer, to facilitate subsequent compacting. The rate of vibratory advancement of the strip-like layer of powder is maintained below over-saturation or flooding rates for the rolling mill i.e., does not exceed the capacity of the rolls, at a given setting, to roll the powder so there is no significant accumulation of powder at the roller nip. The rate is controlled as an inverse function of the power load on the compacting rolls, so that the input to the compacting rolls is adjustable to a level which will result in a substantially continuously uniform output from the discharge side of the compacting rolls.

6 Claims, 8 Drawing Figures

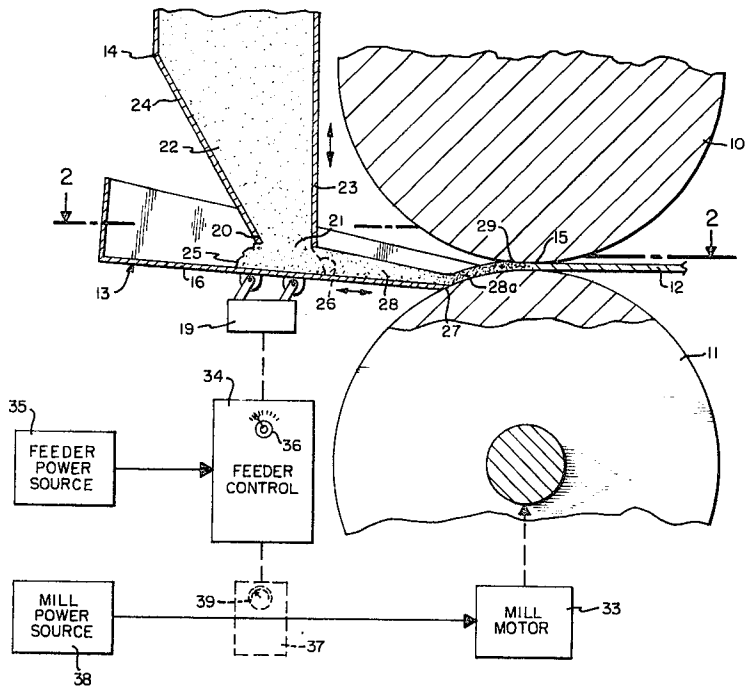


FIG. 1

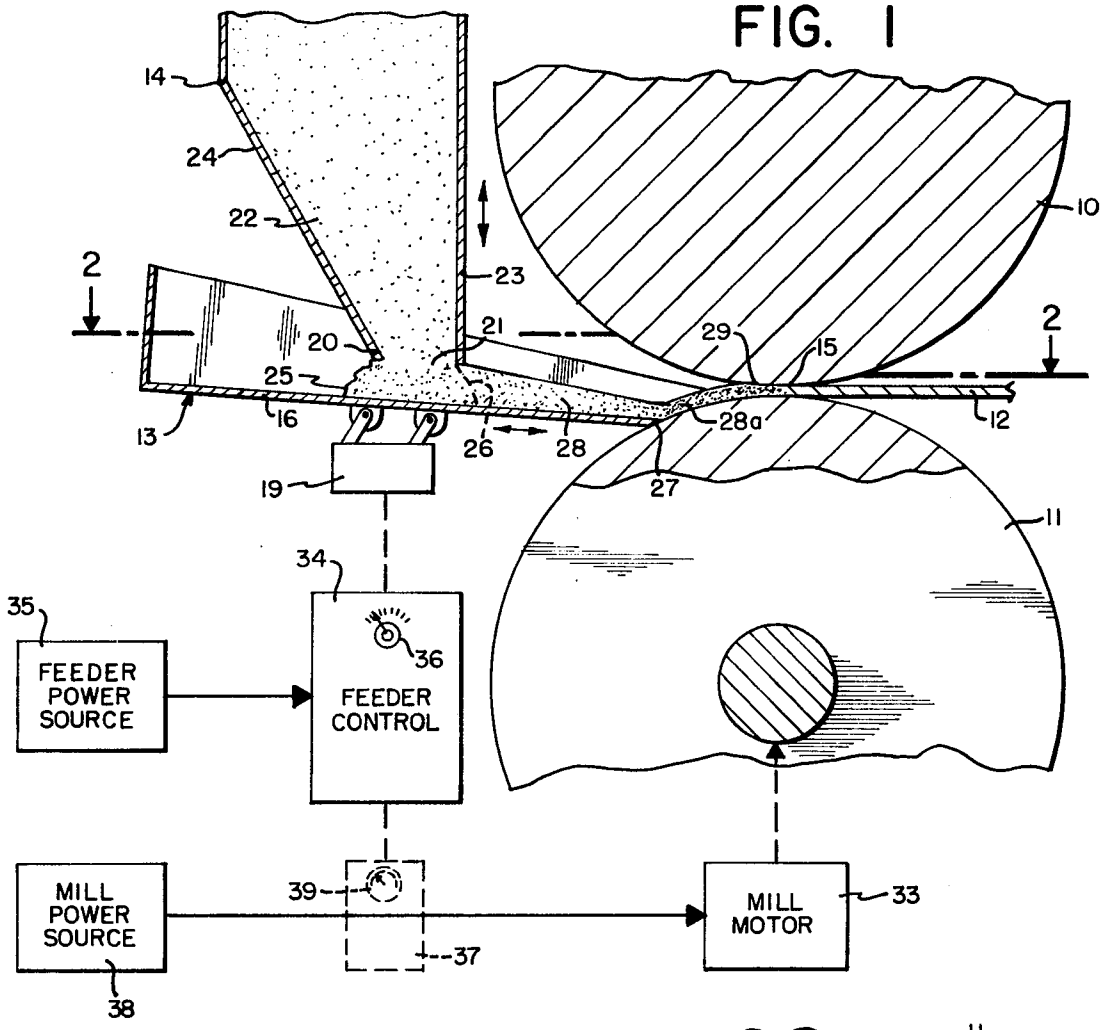
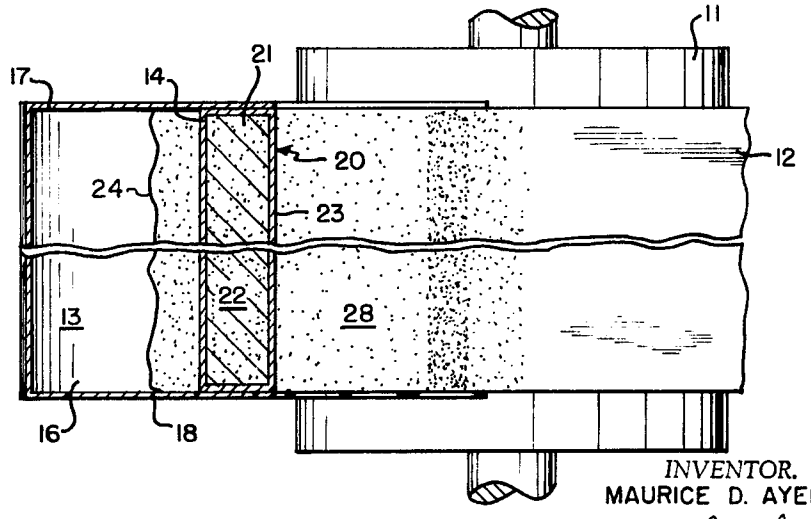


FIG. 2



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FIG. 3a

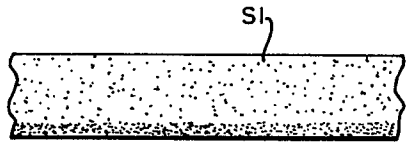


FIG. 3b

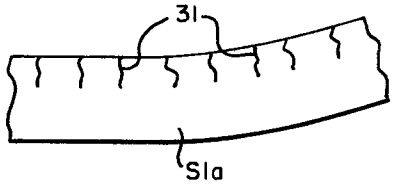


FIG. 4a

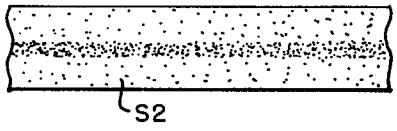


FIG. 4b

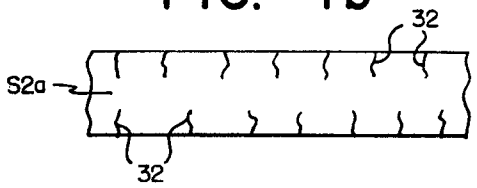


FIG. 5a

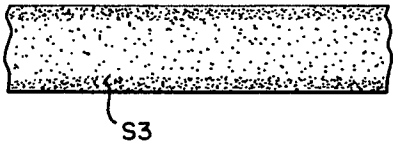
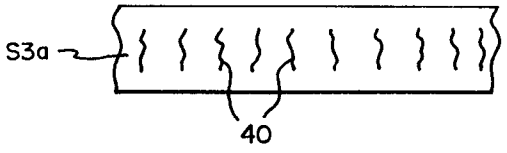


FIG. 5b



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METHOD AND MEANS FOR CONVERTING METAL POWDERS TO CONTINUOUS STRIP FORM

BACKGROUND AND SUMMARY OF THE INVENTION

The art of powder metallurgy, while undergoing substantial development and commercial expansion has, in the past, been largely confined to the production of compression molded parts. That is, metal powders, formed by water or gas atomization or otherwise, typically are converted to finished products by being placed in a suitable mold and subjected to extremely high compression forces. Thereafter, the compression molded parts are sintered and then machined, if necessary, into finished parts. Notwithstanding the ultimate desirability of producing continuous forms from metal powders, great difficulty has been experienced in the conversion of powders to such continuous forms as metal strip, for example, on a practical, commercial basis.

One of the principal shortcomings to conventional techniques for the conversion of metal powders to continuous strip form has been the difficulty in maintaining strip uniformity, both lengthwise and across the strip, on a truly continuous basis. In order to achieve a process which is practical on a commercial scale, it must be possible to operate and control the process to produce, without process interruption, hundreds or perhaps even thousands of feet of metal strip exhibiting uniform characteristics throughout. For example, the strip must be of uniform thickness and density, not only across its width, but also throughout its entire length. Across-the-width uniformity is especially critical since an out-of-tolerance area across the section of the strip can cause severe cracking of the strip during subsequent hot rolling and can render the strip commercially worthless.

In the consolidation of metal powders to a compacted green strip, prior to hot rolling, uniformity of strip thickness is not the only criterion which must be satisfied. The density of the strip and the degree of mechanical working thereof also is significant. Thus, with a sufficiently powerful set of compacting rolls, it may be possible to produce a strip exhibiting a reasonable uniformity in its thickness dimensions. However, if there is variation in the amount of metal passing through the compacting mill, even a uniformly thick compacted strip may exhibit variations in density which could render the ultimate, hot rolled strip useless or of seriously compromised quality. Further, in this respect, when the rolls are required to exert more "work" upon the metal in certain areas than in others, the physical or metallurgical characteristics of the produced strip may vary undesirably from area to area.

The present invention is based in part upon the observation that the production of strip from powdered metal, on a commercially satisfactory basis, requires critical control of the feeding of the metal powder to the input side of the compacting rolls. Thus, the compacting rolls in a conversion process can do no more than process the powdered material delivered to the input side of the roller nip, and if there are variations in the rate and form of the input there will, in general, be impairment of the strip production emerging from the discharge side of the roller nip.

In accordance with one aspect of the invention, the metal powder to be consolidated into strip form by a pair of compacting rolls is supplied to the compacting rolls in a carefully controlled, strip-like form in the first instance. Thus, rather than feed the input side of the compacting rolls with, for example, a bulk or over-saturated supply of metal powder, under a gravity head or otherwise, and relying on the compacting rolls themselves to extract the desired amounts of metal powder for passage through the roller nip, the metal powder is, in accordance with the present invention, converted to a strip-like layer while still in the powder stage and then carefully fed up to the input side of the roller nip at a precisely controlled, saturated rate. The strip-like layer of powder material is controlled to be of uniform thickness and density across its width, and is of an appropriate thickness, as it enters the roller nip, to result in a strip of proper thickness and density when subjected to the compression forces of the roller nip. Only the powder itself passes through the roller nip, so that the compacting rolls are not required to act on the powder through an auxiliary conveyor belt or the like.

As a specific feature of the present invention, a strip-like layer of powder, of controlled configuration and of substantially uniform across-the-width thickness and density, is controllably fed onto the surface of the lower compacting roll of a cooperating pair thereof. The strip-like layer of powder is fed onto the roll surface at a point sufficiently in advance of the roller nip that the space between the rolls at that point is greater than the thickness of the strip. As a result, the deposited strip-like layer initially is conveyed by the lower roll into the roller nip. The rate of deposit on the roll is controlled so as not to exceed the rate at which the strip is compacted by the rolls, so that a "saturation" level of feeding is precisely maintained, but over-saturation or flooding of the powder at the roller nip is reliably avoided.

In accordance with another aspect of the invention, controllable feeding of the metal powder in a strip-like layer to the roller nip is effected by asymmetrical vibratory movement of a supporting tray or platen. By appropriate control over the asymmetrical vibration of the supporting surface, the rate of advance of the strip-like layer of powder toward the roller nip may be precisely controlled. Simultaneously, while the strip-like layer is being thus controllably advanced toward the roller nip, a continuous, progressive consolidation of the powder particles is effected. A number of advantages derive from the vibratory consolidation of the particles during this feeding stage, among which are that the strip-like layer of the powder particles is of minimum thickness at the entry side of the roller nip, for a given thickness of consolidated metal issuing from the discharge side. Moreover, especially where relatively irregular powder particles are utilized in the process, as is contemplated by the preferred aspects of the invention, the powder particles of the strip-like layer become mechanically interlocked to a degree, which assists in the controlled delivery of the strip-like layer into the roller nip.

An additional advantage of significance resides in the fact that during the vibratory feeding stage, the resultant consolidation of the strip-like layer of metal powder increases it density by about 20 percent. This

causes an expulsion of gas from the strip-like powder layer, prior to compacting, which is significantly beneficial in the subsequent roller compacting operation. In this respect, it will be appreciated that a given volume of metal powder contains a large percentage of voids between the powder particles. These voids are, of course, occupied by the ambient gas. During the compression of the metal powder particles into a consolidated metal strip, the contained gas necessarily is displaced from the input side of the roller nip and is expelled through the incoming powder and into the surrounding atmosphere. As the rate of strip formation is increased, the velocity of gas expulsion becomes greater until, at some stage, the movement of the expelled gas can interfere with the disposition of the powder on the incoming side of the compacting rolls. The extent of the problem encountered through the expelled gases is, of course, a function of the volume of such gases contained within a unit volume of in-feeding powder and, by minimizing the volume of contained gas, the rate of production can be correspondingly increased without encountering production difficulties.

In accordance with another aspect of the invention, the vibratory feeding system, which serves to controllably advance a strip-like layer of powder particles toward and into the consolidating roller nip, is controllably varied as an inverse function of the load conditions on the consolidating rolls. This may be accomplished through appropriate electrical control circuitry which, in itself, may be of generally conventional design. The control circuitry can be made sensitive to the electrical power input to the drive motor for the compacting rolls. Thus, an increase in load can indicate that a controlled reduction in the vibratory action of the feeding table is required. A lowering of the rate of powder in-feed will reduce the powder requirements of the rolling mill back toward the nominal predetermined power level. The desired power level for a given set of production requirements may be empirically determined without difficulty.

For a better understanding of the invention, reference should be made to the following detailed description and to the accompanying drawing.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified schematic representation of a metal powder-to-continuous strip conversion mill incorporating the process and the structural features of the invention.

FIG. 2 is a cross-sectional view taken generally along line 2—2 of FIG. 1.

FIGS. *3a* and *3b* are simplified representations of consolidated and hot rolled strip sections illustrating the effects upon the hot rolled strip, of an excess metal density at one edge of the consolidated strip.

FIGS. *4a* and *4b* are simplified representations of consolidated and hot rolled strip sections illustrating the effects upon the hot rolled strip of an excess metal density at the center of the consolidated strip.

FIGS. *5a* and *5b* are simplified representations of consolidated and hot rolled strip sections illustrating the effects upon the hot rolled strip of an excess metal density at both edges of the consolidated strip.

DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to the drawings, the reference numerals **10**, **11** designate upper and lower process rolls of a compacting mill. The construction of the mill is conventional and forms no part of the invention, it being sufficient to note that the mill is of a character to apply uniform, controlled rolling pressure to an incoming supply of metal powder to consolidate the powder into a so-called green strip, designated by the reference numeral **12**. In accordance with the invention, metal powder is supplied to the compacting rollers **10**, **11** by means of a delivery tray **13**, to be described in greater detail, and a supply hopper **14**. The discharge end of the hopper **14** is positioned above the tray **13**, and the discharge end of the tray is, in turn, positioned adjacent but spaced well in advance of the nip **15** of the compacting rollers, as is evident in FIG. **1**.

In accordance with one aspect of the invention, the delivery tray **13** is supported with its bottom wall **16** disposed horizontally or, preferably, tilted a few degrees downward from left to right in the illustration of FIG. 1. A downward incline of approximately 4° appears to be an optimum disposition of the wall **16** for the processing of water-atomized iron and steel powders. However, appropriate adjustment may be provided for if desired. For convenience, the delivery tray **13** thus may be described herein as being disposed at a low negative angle to the horizontal.

The tray **13** is provided with spaced side walls **17**, **18**, and the space between these side walls is related to the desired width of the green strip **12** sought to be produced by the process. In this respect, it is contemplated that the tray **13** may be constructed to be adjustable in width, for the production of different strip widths, or, more probably, there will be a physical substitution of different trays, of different widths, where it is desired to change the width of the strip production.

As illustrated in FIG. 1, the delivery tray **13** is supported, at least in part, by an asymmetrically vibrating motor **19** which, when energized, serves to rapidly vibrate the tray **13** with a component of the vibrational movement being directed in the plane of the bottom wall **16**, in a direction to advance the powder. For reference purposes, the plane of the bottom wall may be referred to as the feeding plane. Typically the feed tray motor may be of the type which causes the forward (left to right) vibrations of the tray to be more effective than the rearward vibrations. This tends to cause an incremental forward advancement of material supported by the tray bottom **16**, with each vibratory cycle of the motor. Precise control over the rate of forward advancement of material on the tray may be effected by controlling the amplitude of vibratory movement of the motor **19**, as will be understood. Vibratory feeding motors of this type are conventionally available. A motor mechanism of suitable construction is available, for example, from the Syntron Company, of Homer City, Pa. The delivery tray **13** is, however, specially constructed to assure accuracy in the formation and feeding of the desired strip-like layer.

As shown in FIG. 1, the feed hopper **14** is disposed above the delivery tray **13** and has a discharge nozzle portion **20** forming a discharge opening **21** which is disposed below the upper extremities of the tray side walls **17**, **18** FIG. 2 but a predetermined distance above

the bottom wall 16 of the tray. The hopper 14 is supported independently of the tray 13 and, most advantageously, is mounted for controlled vertical adjustment, so that the spacing of the discharge opening 21 above the tray bottom 16 may be precisely regulated.

In the system of the invention, the hopper 14 is adapted to retain a suitable supply of metal powder for conversion into strip form, the powder being designated by the reference numeral 22 in the illustration. The powder supply in the hopper may be replenished from time to time, as will be understood, without affecting the continuity of the compacting operation. When the system is in operation, the metal powder flows by gravity downward through the hopper 14 and out through the discharge opening 21. With the equipment in a static condition, only a small supply of powder will flow out through the discharge opening 21, forming a small mound of powder directly underneath the opening, until the resistance of the powder to further flow balances the effective "head" of the powder tending to flow downward through the nozzle opening. As reflected in FIG. 2, the discharge opening 21 extends substantially entirely across the delivery tray 13 and, desirably, is rather narrow in the direction of the strip axis. Accordingly, in the static condition of the equipment, the small mound of powder built up underneath the discharge opening 21 typically extends entirely across the bottom of the delivery tray 13 and for a short distance beyond the front and back walls 23, 24 of the hopper nozzle. The latter condition is reflected by the sloping line 25, which illustrates the back wall of the powder mound, and a dotted line 26 indicating the approximate location of the front wall of the powder mound in the static condition of the equipment. When the delivery tray 13 is activated by the motor 19, the asymmetrical vibration of the tray causes the powder to be advanced incrementally forward (left to right in FIG. 1) along the bottom wall 16 of the tray, with additional powder being fed in from the hopper 14 to replace that which is incrementally advanced.

In accordance with one aspect of the invention, the lower edge of the hopper nozzle front wall 23 forms a leveling bar for the incrementally advanced powder. This lower edge is disposed horizontally across the tray bottom, a uniform distance above the bottom surface, so that the incrementally moving powder is caused to assume a strip-like form as it is advanced toward the discharge end 27 of the tray. As the strip-like layer of powder is advanced along the surface of the delivery tray, the vibratory action of the tray effects a gradual consolidation of the powder particles, so that the strip-like layer, designated by the numeral 28, is more dense at the discharge end of the tray than at the discharge end of the hopper nozzle. This is especially advantageous in the process, since it imparts greater coherence to the strip-like powder layer as it approaches the roller nip, minimizes the displacement of gas from the material during the subsequent compaction by rolling pressure at the nip, and it also reduces the thickness of the powder layer at the entry side of the roller nip to facilitate the controlled movement of material into the nip.

As reflected in FIG. 1, the discharge end 27 of the delivery tray approaches into near contact with the surface of the lower compacting roll 11 at a distance well in advance of the roller nip. As one practical limit condition, the distance is sufficiently in advance of the roller nip that the space between the rollers 10, 11 at such distance is greater than the thickness of the strip-like layer 28*a* as it is discharged from the delivery tray. Thus, the strip-like layer 28 is caused to be deposited onto the surface of the lower compacting roll and is actually conveyed forward by that roll until the layer is engaged at 29 by the surface of the upper roll 10 and compacting of the consolidated powder is commenced. As another practical limit condition, the distance should not be so great that the strip-like layer is caused to assume a large angle with respect to either the bottom wall 16 or the horizontal. Thus, if the strip-like layer is caused to undergo an excessively large change in direction as it is deposited on the roller 11, there can be an undesired change in the physical arrangement of powder particles in the strip-like layer. Likewise, if the surface of the roll 11 makes too great an upward angle with respect to the horizontal, slippage may occur between the roll surface and the powder layer. Under most conditions, satisfactory operation is achieved by depositing the strip-like layer on the roller 11 at a distance of not more than about 0.20 of the roll diameter in advance of the plane containing the roll axes. With such an arrangement, the angle between the tray bottom 16 and the roll surface will be less than 25°.

Advantageously, the discharge end 27 of the delivery tray is located as close as practicable to the roll surface, to enable the strip-like layer of consolidated powder to bridge over the gap without significant deterioration of its strip-like form. A clearance of one-thirty second of an inch generally is satisfactory.

The powder feeding system of the invention is especially advantageous in achieving across-the-width uniformity in the strip-like layer 28*a* which is laid on the roller 11 for compacting. Such across-the-width uniformity is of critical significance to a successful production operation, and difficulties heretofore experienced in achieving such uniformity may well account for the limited commercial development, thus far, of powder-to-strip production plants. In this respect, the infeeding of powder must be so carried out that the compacted strip emerging from the discharge side of the rolls 10, 11 is of uniform density as well as of uniform thickness.

In FIG. 3*a*, there is shown a compacted strip S1 which is so formed that there is a slightly greater quantity of metal at the shaded lower edge than at the upper edge (e.g., greater metal density in a compacted strip of uniform thickness). When this compact S1 is subsequently hot rolled, the excess metal in the lower edge will cause that edge to elongate to an extent greater than the upper edge. This is reflected in the hot rolled strip S1*a* of FIG. 3*b*. The resulting hot rolled strip not only tends to have a sidewise curl, but also evidences cracking along the lower density upper edge, as reflected at 31.

Compacted and hot rolled strips S2 and S2*a* of FIGS. 4*a and 4b* reflect increased metal content in the shaded center portion of the compact S2, resulting in significant edge cracking at 32 along both edges of the hot rolled strip S2*a*. Likewise, the shaded edges of the compact S3 reflect increased metal content at both edges, resulting in center cracking at 40 in the resulting hot rolled strip S3*a* of FIG. 5*b*.

Any of the defects reflected by FIGS. 3*b* –5*b* could result from the hot rolling of compacted strip that was of uniform thickness but of non-uniform across-the-width density. Such variation in density can be largely avoided, however, by following the techniques of the invention.

In accordance with one aspect of the invention, the space relationship between the discharge opening **21** of the powder feed hopper 14 and the roller nip 15 should be kept as short as practicable, consistent with the objective of effecting a vibratory consolidation of the powder from its normal density to a heavier (e.g., 20 percent greater) density more advantageous for efficient roller compacting. In this respect, excessive vibration of the powder will tend to effect a classification of powder particles, with the smaller particles seeking the lower levels of the strip-like layer and the larger particles tending to occupy the upper levels of the layer. As will be understood, while such particle size classification may be useful for certain specialty production, it would be considered detrimental to the production of most conventional strip materials. In a practical embodiment of the invention, satisfactory results were obtained in the production of wrought iron strip from iron powder with the discharge opening **21** located about six inches away from the nip 15 of eleven inch diameter compacting rollers. The optimum spacing for various powder metals may be readily determined by empirical observations, bearing in mind the considerations set forth above, and appropriate horizontal adjustability may be provided in the mounting of the hopper 14 to accommodate the requirements of the mill.

As previously indicated, one of the fundamental requirements of a commercially acceptable metal powder-to-strip production process is its ability to turn out a compacted green strip of uniform characteristics, not only minute to minute, but day to day, week to week, etc. A run of strip production may be rendered worthless or even impossible to hot roll if there are even occasional out-of-tolerance variations. To this end, the process of the invention enables the rate of in-feeding of the strip-like powder layer 28 to be automatically and continuously controlled as a function of the performance of the rolling operating itself. Thus, not only is the character of the strip-like powder layer critically controlled across the width of the strip, but also the rate of advancement of that layer toward the roller nip is carefully maintained at a saturation level (meaning that the thickness, density and rate of in-feed of the strip-like layer of powder toward the roller nip is at all times in close correspondence with the rate at which in-specification compacted green strip is being produced by the rolls, avoiding both over-saturation or flooding, on the one hand, and roll starvation, on the other).

It has been determined that a particularly effective measure of production performance in the rolling mill is the level of power required to drive the mill. In other words, if the input of powder to the roller nip is at an excessive rate, the density of the produced strip will be too high, and this condition will be reflected in thicker and high density strip. This causes unsatisfactory results. Conversely, where the infeed rate is too low, the roller compacted green strip will be insufficiently dense, and this condition will be reflected by a weak strip that will break during subsequent processing.

In accordance with one specific aspect of the invention, a control system is provided, in which the operation of the vibratory feeding motor **19** can be operated manually according to observed mill load or can be coupled with the operation of the mill motor **33**, so as to be varied as an inverse function of the mill motor power requirements. Thus, in a practical system according to the invention, illustrated schematically in FIG. 1, the delivery table motor **19** is regulated by a feeder control, generally designated by the numeral **34**, which is supplied by a suitable power source **35**. The feeder control is provided with two principal control inputs: one is a manual control setting **36** and the other is the output of a power sensor element **37** coupled in the line between the mill motor **33** and its power source **38**. The power sensor element is provided with a suitable indicating meter **39**, which may be a conventional ammeter.

In the control system of FIG. **1**, a determination is made of the desired power level at which the mill should be operated, to produce a green strip of desired characteristics from a metal powder of given characteristics. Initially such a determination may be made empirically, or it may be made the subject of calculation, based upon historical experience. Once the desired operating power level is determined, the manual setting **36** of the feeder control **34** is adjusted to obtain the desired power reading on the meter **39** (i.e., by increasing the vibratory amplitude of the feeder motor 19 with the control 34, the power requirements of the mill motor are increased, and vice versa). After the desired power indication is reached, the control system of FIG. 1 can be set to automatically monitor the mill motor power consumption and, in response to variations therein, to cause inversely related variations in the control output of the feeder control 34. Thus, increasing power requirements of the mill motor automatically will cause a corresponding reduction in the vibratory amplitude of the delivery table motor 19 and thereby incrementally reduce the rate of inflow of the powder layer. Decreasing power requirements at the mill motor will, on the other hand, reflect "starvation" of the compacting rollers and will automatically result in an incremental increase in the in-feed rate by increasing the vibratory amplitude of the table motor 19.

The continuous monitoring of the in-feeding of a layer of metal powder to the consolidating rollers of a strip mill, whether accomplished manually or by automatic control, is of particular importance, in that it enables the powder to be supplied in a strip-like form which is closely correlated to the compacted green strip emerging from the discharge side of the rollers. This process technique enables a production operation to be carried out on a practical, commercial basis, producing large tonnages of uniform strip material. Of course, there may be other criteria than mill motor power consumption to reflect green strip characteristics, and any such measurable criteria could be utilized in effecting monitored regulation of the feeder control 34. In this respect, however, strip thickness is generally not a usefully measurable criterion, because the green strip typically has a density of less than 100 percent, and strip thickness could remain constant while wide variations were occurring in the important characteristic of strip density.

In a typical strip production process according to the invention, for the production of wrought iron strip, the starting material advantageously is a low-oxide iron powder of irregular or angular (as distinguished from round or very smooth) shape. Powder especially suitable for the purpose may be produced in accordance with the teachings of my earlier U.S. Pat. No. 3,334,408, granted Aug. 8, 1967, and of my copending U.S. Pat. application Ser. No. 855,096, filed Sept. 4, 1969, although this present invention is by no means limited to the use of powders produced according to that patent or application. A typical low carbon iron powder produced in accordance with my copending application Ser. No. 855,096 might have an analysis of:

Carbon	0.05%
Oxygen (alcohol dried powder)	0.136%
Manganese	0.24%
Silicon	0.12%
Sulphur	0.031%
Phosphorus	0.007%

The powder typically would be comprised of particles almost exclusively minus 40 mesh and not more than about 40 percent minus 325 mesh (U. S. Sieve Series, A.S.T.M. spec. E-11-61). Such powder might have an initial apparent density of about 3.1 grams per cubic centimeter. After vibratory consolidation on the delivery tray 13, but before entry into the roller nip, such powder would have an apparent density of about 3.7 g/cc, an increase of about 20 percent over the initial apparent density. After roller compacting, the green strip 12 emerging from the discharge side of the roller nip would have a density of about 6.3 g/cc, (for ferrous powders) assuming the green strip to have been compacted to the desirable range of approximately 75–80 percent solid density.

In a production operation as outlined above, the height setting of the hopper discharge nozzle 20 is such that the thickness of the strip-like powder layer 28*a*, just before entering the roller nip, bears approximately the same relation to the thickness of the green strip as the green strip density bears to the vibratory-consolidated density of the powder (i.e., approximately 6.3:3.7 in the example). This minimizes the slippage and internal turbulence in the powder layer as the roller consolidation commences.

In a typical small production mill useful for the practice of the invention, compacted strip may be continuously produced from iron powders, for example, at rates up to 100 feet per minute. Using compacting rolls of about eleven inch diameter, compacted strip may be readily produced in gages from about 0.075 inch down to about 0.025 inch, in densities ranging from about 70 percent (soft) to about 90 percent (hard). The compacted green strip can be trimmed along its edges, and an advantageous facility for that purpose is disclosed and claimed in U.S. Pat. No. 3,328,166, granted June 27, 1967. Thereafter, the green strip usually is treated in a controlled atmosphere and hot rolled to 100 percent density and to a desired final gage.

The process of the present invention derives important advantages from the fact that, in the operation of converting metal powders to compacted green strip, precise control is had over both the form and the nature of the powder being advanced toward the compacting roller nip. The arrangement is such that the incoming powder, which is a flowable granular material, is supplied to the roller nip 15 in a strip-like configuration, already partly consolidated and having dimensional relationships closely consistent with the strip to be produced. The delivery of powder in strip-like form is effectively isolated from the basic supply of the powder material in a hopper or the like through the interposition of a delivery tray 13 extending at a low negative angle of about 4° from the hopper outlet. The delivery tray is asymmetrically vibrated to advance the powder from the hopper discharge in a carefully controlled strip-like layer and simultaneously to effect a vibratory consolidation of the powder. The partial consolidation is highly advantageous in that inclusions of ambient gas are reduced, minimizing gas expulsion problems when the strip subsequently is roller compacted from a density of, say, 47 percent to a density of about 80 percent. The vibratory consolidation also imparts a high degree of interlocked integrity to the strip-like form of the loose powder, so that its movement into the roller nip does not occasion a disintegration of the strip-like form of the powder. The latter consideration is, of course, aided materially by so controlling the rate of in-feed of the strip-like powder layer, continuously and automatically, that the incoming layer bears the proper thickness and density relationships to the emerging green strip. The flow of materials into and through the roller nip, in the process of the invention, may be somewhat analogized to a laminar, as distinguished from turbulent, flow.

A particularly important feature of the invention resides in providing for a synchronous or saturated infeed of a strip-like layer of powder onto the surface of the lower compacting roller, in advance of the roller nip. The lower roll then actually conveys the strip-like layer of powder into the nip at a rate which corresponds closely with the rate at which compacted strip is formed. This contrasts significantly with more conventional "over-saturation" feeding techniques, in which the roll bight is flooded with an excess of powder, and powder is, in effect, fed into the nip by the friction of the roll surfaces. In the conventional process, the character of the compacted strip is excessively dependent upon frictional conditions (e.g., powder flow, roll surfaces, etc.) and is very difficult to control. By utilizing the lower compacting roll to convey powder, already in precisely controlled strip-like form, under conditions of controlled saturation, "-flooding" or "starvation" of the nip is avoided and compacting of the powder is accomplished with a minimum disturbance of the powder from its deposited, strip-like form.

By making possible the controlled production of green strip having uniform characteristics over extended production, the process of the invention renders feasible on a high tonnage commercial scale the production of strip materials from metal powders. Thus, the process of the invention is realistically utilizable in meeting the high tonnage requirements of commercial iron and steel strip production, for example, enabling such strip materials to be produced on an economically advantageous basis as compared to more conventional techniques.

It should be understood, of course, that the specific form of the invention herein illustrated and described is

intended to be representative only, as certain changes may be made therein without departing from the clear teachings of the disclosure. Accordingly, reference should be made to the following appended claims in determining the full scope of the invention.

I claim:

1. The method of converting metal powders to consolidated strip form, which comprises

a. feeding metal powder from a supply thereof onto a delivery surface,

b. asymmetrically vibrating the power along a substantially horizontal feeding plane defined by the delivery surface to effect controlled advancement of the powder,

c. leveling the advancing powder to a predetermined thickness and confining the edges of the advancing powder to form a layer of strip-like form having highly uniform across-the-width thickness and density,

d. continuing to advance the strip-like layer of leveled powder in said feeding plane by said asymmetrical vibration and thereby effecting vibratory pre-consolidation of the strip-like layer,

e. depositing the strip-like layer of powder on the lower one of a pair of compacting rollers while substantially retaining the strip-like form of the advancing powder layer,

f. advancing the strip-like layer on and by said roller into the nip of said pair of rollers,

g. subjecting the strip-like layer to sufficient rolling pressure in said roller nip to form a compacted green strip, and

h. variably controlling the rate of said controlled advancement of the powder in accordance with the performance of the rolling pressure step such that the thickness, density and rate of in-feed of the strip-like layer are maintained in close correspondence with the production of compacted green strip.

2. A method as recited in claim 1, further characterized by

a. the vibration step being carried out at variable amplitude, and

b. said amplitude being controlled under a given set of powder and green strip characteristics as a predetermined function of the power required to carry out said rolling pressure step.

3. The method of claim 1, further characterized by

a. said strip-like layer being deposited on said roll surface at a distance in advance of the roller nip not more than about 0.20 roll diameter from the center of the roller nip.

4. The method of claim 1, further characterized by

a. said feeding plane extending substantially to said roll surface and being downwardly inclined in the direction of powder advance at an angle of about four degrees to the horizontal.

5. A method as recited in claim 1, further characterized by

a. said feeding step being carried out by gravity flow from said supply, and

b. adjustably controlling the leveling step for regulating the initial thickness of said strip-like layer for adjustably controlling the thickness of the rolled green strip.

6. A method as recited in claim 1, further characterized by

a. said strip-like layer being directed through an angular change of direction of less than about 25 degrees as it is deposited on said roller from said feeding plane.

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