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CONTROL SYSTEM FOR MAXIMIZING THE PRODUCTION
OF A MATERIAL FORMING PROCESS

3,286,302

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2 Sheets-Sheet 1

Fig. 1

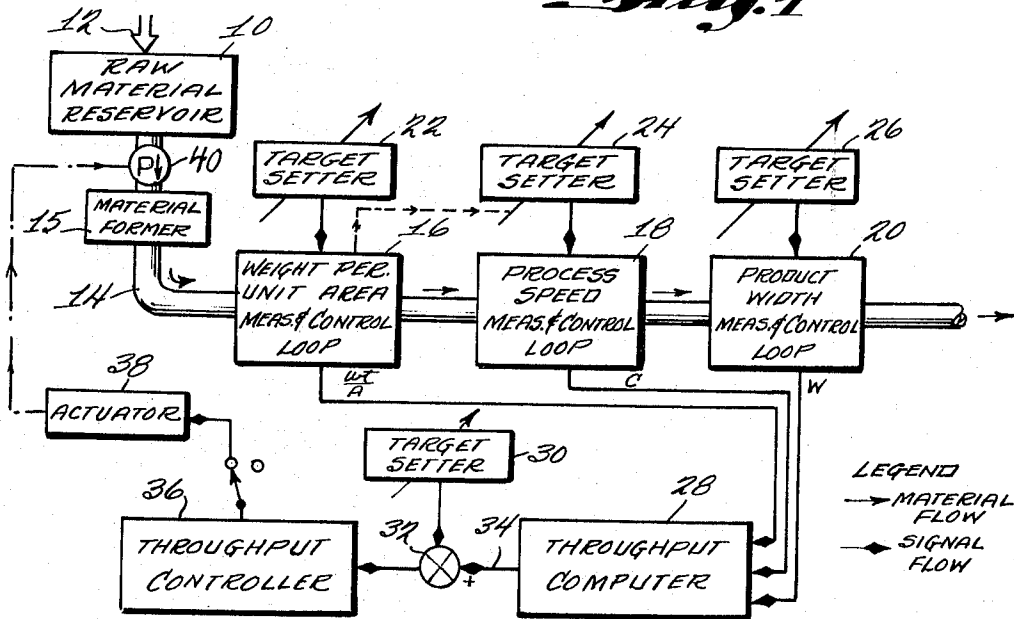
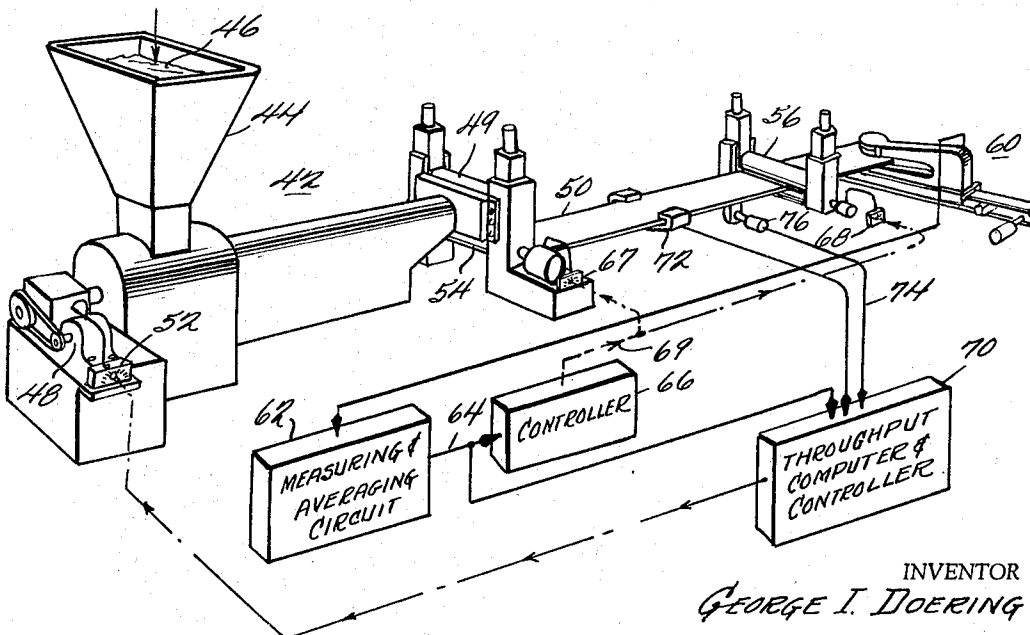


Fig. 2

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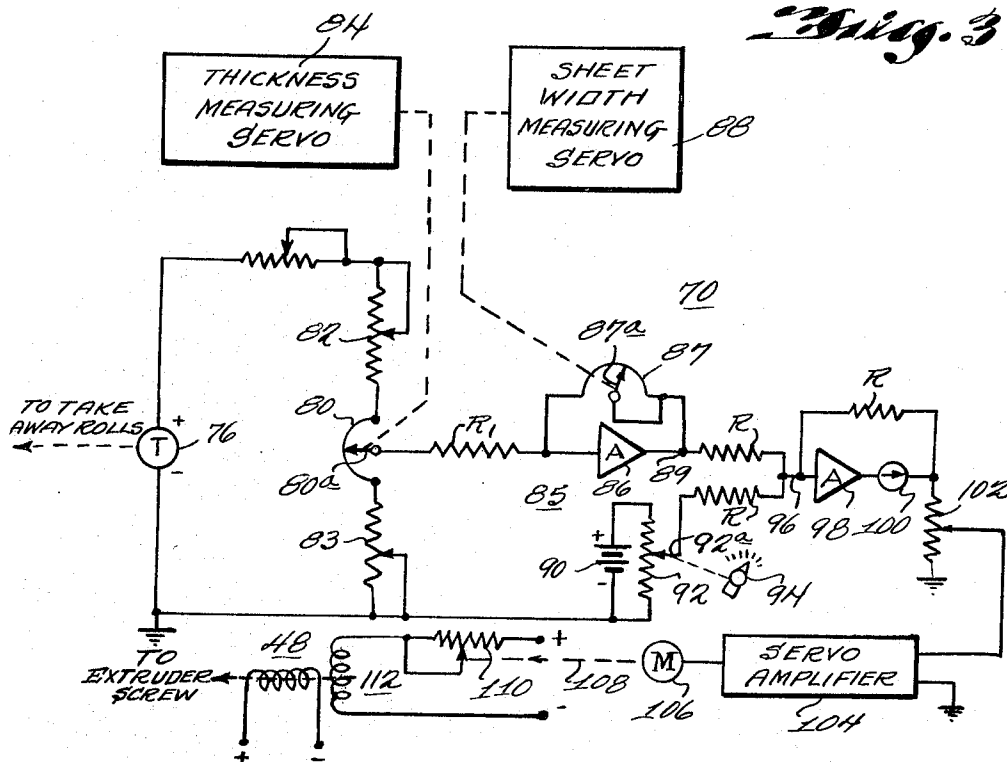
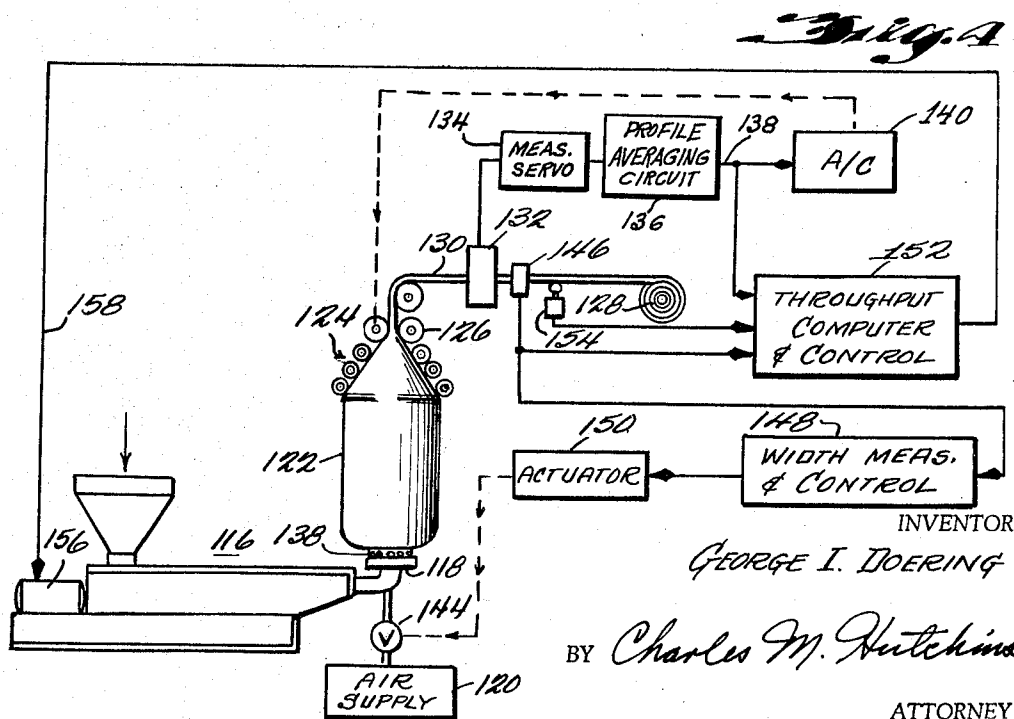
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OF A MATERIAL FORMING PROCESS

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3,286,302

CONTROL SYSTEM FOR MAXIMIZING THE PRODUCTION OF A MATERIAL FORMING PROCESS

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8 Claims. (Cl. 18—2)

This invention relates generally to automatic control systems for plastic extrusion processes and more specifically to a novel method and means for maximizing the production rate of such processes.

Most industrial processes are designed to receive raw material of one sort or another and to operate on this raw material to form a product having certain desirable characteristics such as a uniform density, thickness, width or composition. This is true in the paper making, cigarette manufacturing, and plastic extrusion industries. In these industries, it has been the practice to utilize various measuring and controlling systems to insure that any variations in the received raw material will not be transmitted to the final product. Usually by measuring one or more of the variables in the material after it is formed, it is possible to correct by means of adjusting elements in the forming apparatus so as to produce a uniform output. For example, in the cigarette manufacturing industry, variations in the density and composition of raw tobacco entering the hopper have caused the manufactured cigarette rod to vary in weight. Radiation gauges have been used to determine the weight per unit length of a cigarette rod as it leaves the forming apparatus. To compensate for variations in the unit weight of the cigarette rod, control is exerted on the tobacco feeding apparatus. This technique is more adequately explained in U.S. Patent 2,954,775 issued to S. A. Radley et al., on October 4, 1960, and assigned to the same assignee as the present invention. In the plastic extrusion industry, raw material is introduced into an extruder which softens it and forces the semi-liquidous material through a die element. The die may be of the linear type that provides a sheet which can be drawn away by take-away conveyor rolls or the die may be of the circular type in which the plastic is forced through and air or liquid is admitted to form a tube or bubble. The bubble is then flattened to form a sheet of double thickness. In these applications, it is usually desired to maintain a constant sheet thickness. Accordingly, it has been the practice to measure the thickness of the sheet and make corresponding adjustments of either the take-away or draw-off speed or the extruder screw speed forcing raw material through the die. U.S. Patent 3,015,129, issued to W. C. Hays et al., on January 2, 1962, and assigned to the same assignee as the present invention, describes such a system.

While these control systems produce an output product having certain desirable characteristics, they are usually not operated so as to provide the highest production rate capable of the machinery for which it is designed. Not only is it desirable to have an output which is uniform, but it is also economically important to produce as much material per unit time as possible. While the customer must buy more raw material to operate his system in such a manner, the cost is off-set by the increased quantity of salable material the equipment produces when so operated. Due to the complex interacting adjustments of the processing equipment, it is difficult for operating personnel to make manual adjustments so as to maximize the desirable throughput.

Accordingly, the present invention cooperates with the aforementioned measuring and controlling systems by making measurements on the product and controlling the

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throughput or mass per unit time being run to maximize the production rate. The present invention is embodied in the plastic extrusion processes described above but its utility is evident in other processes as well.

This invention is an improvement over the extruder control system described in my copending application Serial No. 79,198, filed December 29, 1960, now Patent No. 3,150,213, entitled "Regulation of Extruder Systems" and assigned to the same assignee as the present invention.

Accordingly, it is a primary object of the present invention to provide a measuring and controlling system for maximizing the throughput of a material-forming process, for example a plastic extrusion process.

It is also an object of the present invention to provide such a system which can be applied to industrial lines already in operation.

It is yet another object of the present invention to provide such a system that can be readily constructed and easily calibrated.

These and other objects of the present invention will become more apparent upon reference to the following description when taken in conjunction with the drawings, in which:

FIG. 1 is a block diagram of the present invention;

FIG. 2 is a perspective view of a plastic sheet extruder controlled in accordance with the present invention;

FIG. 3 is a schematic circuit diagram of a throughput computer and controller useful in the control system of FIG. 2; and

FIG. 4 is an elevation view, partly schematic, of a plastic blown film extruder controlled in accordance with the present invention.

With reference now to the drawings and particularly to FIG. 1, there is shown a reservoir 10 for receiving a quantity of raw material as indicated by the large arrow 12. The material to be processed is carried by a conduit 14 through the various stages of forming and preparation as indicated at 15. Three processing operations that may be controlled are denoted by the three large blocks 16, 18 and 20. One block might be a measuring and control loop affecting for example, the weight per unit area of the final product, another block the processing rate, and yet another, an exterior dimension such as the width of the final product. The desired weight per unit area, processing speed and product width may be set by means of the three target setters shown at 22, 24 and 26. Each of the three measuring and controlling systems may be independent or the weight control loop 16 may adjust the speed target 24, for example.

It is not only desirable to maintain certain product dimensions but also to provide as much product per unit time as possible. This figure of production is commonly referred to as throughput.

The throughput M of this process may be computed as follows:

$$M = \frac{Wt}{A} \times C \times W \text{ lbs. per hour}$$

Where Wt/A is the weight per unit area, C is the speed, and W is the width of the product. Since the desired physical characteristics of the product are established by the target setters 22, 24 and 26 and regulated by the respective control loops 16, 18 and 20, it remains only to compute the process throughput and control the inflow of raw material accordingly. In accordance with the present invention, a throughput computer 28 receives the weight per unit area, the speed and the width signals from the respective control loops 16, 18 and 20 and computes the product of these signals in a manner described hereinafter. The throughput value desired from the process can be set on the target setter 30, the output of which

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is compared at 32 with the measured throughput signal on line 34. When the computed throughput is not identical with the desired throughput, control action may be exerted by the controller 36 and actuator 38. The construction of controller 36 as well as others hereinafter described may be found in U.S. Patent 2,895,888 issued July 21, 1959, to D. E. Varner and assigned to the same assignee as the present invention. It is basically a discontinuous reset controller providing an ontime operation of actuator 38 proportional to error. A continuous controller may be used with equal utility. Such a controller is described in U.S. Patent 2,955,206 issued October 4, 1960, to Philip Spergel et al. and assigned to the same assignee as the present invention. Control is proportional to the time integral of the measured error.

To control throughput, one must ultimately make adjustments of the amount of raw material being added per unit time to the process as through a pump means 40. A reduction in throughput causes the error signal to increase in one direction thereby making the actuator 38 increase the output of the pump 40. An increase in throughput over that desired causes the controller 36 to reduce the pump output. It can be seen that the present invention serves to provide both a uniform output product as well as to maximize the amount of uniform material processed per unit time.

In the embodiment shown in FIG. 2, the present invention operates in conjunction with a thickness measuring and controlling loop for a plastic sheet extruder. This apparatus is more fully explained in U.S. Patent 3,015,129 to W. C. Hays et al., supra. In this technique, the width of the output product is maintained essentially constant and the weight per unit area measuring system is coupled to the processing rate control system. There is shown a conventional extruder 42 having a hopper 44 for storing a supply of plastics ingredients 46. A motor 48 serves to force the plastic material through a linear die 49 to form a flat sheet 50. The speed of the motor 48 may be controlled by conventional means such as by a rheostat 52 in the field circuit of the motor. A pair of polishing rolls 54 and pull rolls 56 are used to remove the sheet after it is extruded by the die. A scanning radiation gauge 60 together with the measuring and averaging circuitry 62 serves to provide a signal proportional to the average thickness of the sheet on line 64. It is herein noted that thickness t is related to the weight per unit area and density ρ by the following formula:

$$Wt/A = \rho t$$

Therefore, while the radiation gauge measures sheet weight per unit area, it reads out thickness when the density is constant. A controller 66 changes the speed of the polishing rolls and pull rolls whenever the average thickness value differs from a desired value therefor. Any difference actuates the controller 64 which is mechanically connected to the field rheostats 67, 68 on the two roll stands as indicated by the dotted line 69.

If the plastic driving means is maintained constant by the main motor 48, the effect of a combined roll speed adjustment is to vary the thickness of the sheet 50 as it is pulled from the die. In accordance with the present invention the speed of the extruder screw motor 48 is varied by a throughput computer and control unit 70 which receives data from the process by means of sensing elements located thereon. For example, the thickness information is provided by monitoring line 64, slight variations in the width of the pulled sheet may be sensed by a measuring unit 72 such as manufactured by Askania Regulator Company and marketed under the name of Jet Pipe Relay. A speed-functional signal is generated by a conventional tachometer 76 mounted in tractive engagement with the sheet as it passes between the roll stands 54, 56. This signal is transmitted to unit 70 over line 74.

The co-action of the throughput and thickness control

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loops of the present invention will be seen from the following description and operation. Assume that the thickness controller 66 is providing a sheet at the desired thickness but the throughput of the process is less than that desired. The throughput controller 70 decreases the field resistance of the main motor of the extruder, thereby forcing more material per unit time into the extruder and out the die. This causes a momentary increase in the thickness of the pulled sheet 50. When the effect of this increase is detected by the radiation gauge 60, the thickness controller 66 increases the relative speeds of the roll stand motors to bring the output sheet thickness back down to the desired value. The measured throughput increases since the processing rate is much greater than before.

A simple throughput computer and controller suitable for unit 70 is shown in greater detail in FIG. 3. The output potential of tachometer 76 is impressed across a thickness slidewire potentiometer 80 in series with resistors 81, 82, and 83. Arm 80a of the slidewire 80 is positioned by a thickness measuring servo 84 located in the measuring block 62 shown in FIG. 1. The potential on the arm 80a is applied to a width setting circuit 85 including a high gain amplifier 86, an input resistance R_1 and an adjustable feedback resistance such as the slidewire 87. The position of slidewire arm 87a is varied by a sheet-width measuring servo 88 responsive to the signals developed by the width gauge 72. Alternatively, if the sheet width is constant, then a fixed resistance can replace the sheet width slidewire 87, thereby simplifying the circuit. With this circuit, the potential existing at the tap 80a is attenuated by the ratio of the feedback resistance 87 to an input resistance R_1 and the signal at point 89 is proportional to the throughput of the process. A throughput target setting device may comprise a battery 90 and potential divider circuit provided by means of a variable potentiometer 92, the tap of which is adjustable by means of a control knob 94. The measured throughput signal is suppressed by the reference voltage on arm 92a, and the junction 96 at the input to amplifier 98 rests at a potential proportional to the difference between the measured and the desired throughput values. Identical input and feedback resistors R provide a unity transfer function, enabling a meter 100 to indicate the throughput error. A portion of the error signal is tapped off by a variable resistance 102 and coupled to a servo amplifier 104. Servo amplifier 104 in turn drives a servomotor 106 that is mechanically coupled, as indicated by the dotted lines 108, to a rheostat 110 connected in the field circuit 112 of extruder screw motor 48.

The present invention may be used with equal utility in the blown film extrusion process illustrated in FIG. 4. In this type of extrusion process, the raw material is forced through an extruder 116 and out an annular die 118. Air from a supply 120 is forced through the center of the die to blow the liquid plastic into a large bubble 122. The bubble is thereafter flattened by pinch rolls 124, drawn away by means of a pair of take-away conveyor rolls 126 and collected on a wind-up reel 128. In some applications, the die 118 is rotated to eliminate streaks tending to cause build up on the wind-up reel. The double thickness of the flattened bubble 130 is measured by a radiation gauging device 132 and associated servo 134. If the die is rotated, the gauge can be located at the edge of the sheet 130 to determine a true profile of the die adjustment. Some profile averaging can be used at 136 to determine the average value of thickness of sheet produced and present it on line 138. This technique is more fully explained in Serial No. 309,631, filed September 18, 1963 by William Palmer and assigned to the same assignee as the present invention. An automatic control system 140 may be used to adjust the take-away speed of rollers 126 in accordance with the average profile signal on line 138.

The width of the output sheet can be controlled by

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means of a valve 144 admitting air into the center of the die 118. A width gauge 146 and associated controller 148 may be used to make this adjustment via an actuator 150. By increasing the air pressure a larger bubble is formed which when flattened produces a wider sheet 130. 5

The width signal from the gauge 146 is also coupled to a throughput computer 152 along with the output signals of the thickness profile average computer 136 and a tachometer 154. Control can then be exerted on an extruder screw motor 156 over line 158 in accordance with the computed throughput value. The operation of this embodiment is similar to that described above. Briefly, the product thickness and width are maintained by their respective measuring and control loops and the overall production rate is maximized by the throughput computer and control system of the present invention. 10 15

While the present invention has been shown and described in conjunction with a sheet extrusion process and a blown film process, it may be used with equal utility in other bi-oriented extruding applications. 20

The present invention is described in conjunction with a particular application and as utilizing specific apparatus. Nevertheless, the disclosure should be recognized merely as one example since several modifications may be made therein without departing from the spirit and scope of the present invention or sacrificing any of its attendant advantages. 25

I claim:

1. Apparatus for increasing the production of an industrial process line, said line receiving a supply of raw material for providing a continuous product having a uniform weight characteristic, said apparatus comprising:
 - means for forming said material into said continuous product,
 - means for feeding said material through said forming means at a controllable rate to vary the production rate of said product,
 - means responsive to said weight characteristics and to said production rate of said product for providing a signal proportional to the throughput of said process line, and
 - means responsive to said throughput signal for varying said material feed rate.
2. Apparatus for increasing the production of an industrial process line, said line receiving a supply of raw material for providing a continuous product having a uniform weight characteristic, said apparatus comprising:
 - means for forming said material into said continuous product,
 - means for feeding said material through said forming means at a controllable rate to vary the production rate of said product,
 - means responsive to said weight characteristic and to said production rate of said product for providing a signal proportional to the throughput of said process line, and
 - means responsive to said throughput signal for maximizing said process throughput.
3. Apparatus for increasing the uniform production of a plastic extruder comprising:
 - a sheeting die,
 - pump means for forcing viscous plastic material through said die to form a sheet,
 - take-away means for withdrawing said sheet from said die,
 - a first driving means for said pump means,
 - a second driving means for said take-away means,
 - means for adjusting the speed of said second driving means relative to said first driving means,
 - a radiation gauge positioned after said take-away means for providing a signal proportional to the weight per unit area of said sheet,
 - first controller means energized by a predetermined value of said weight per unit area signal for control-

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ling said relative speed adjusting means to maintain the mass flow of said sheet substantially constant, means for measuring the speed of said sheet leaving said take-away means,

means to maintain the mass flow of said sheet substantially constant for measuring the width of said sheet, computer means for providing a mass flow signal equal to the product of said weight per unit area, said speed and said width measurements, means for adjusting the speed of said first driving means, and second controller means energized by a predetermined value of said mass flow signal for controlling said first driving means speed adjusting means.

4. Plastic sheet extrusion apparatus comprising a sheeting die,
 - adjustable pump means for forcing viscous plastic material through said die to form said sheet,
 - gaging means located after said adjustable sheet conveyor means responsive to generate a first signal proportional to the weight per unit area of said sheet,
 - adjustable conveyor means for withdrawing said sheet away from said die at a controllable speed,
 - means responsive to said first signal for adjusting the speed of said conveying means relative to the rate of said plastic material pump means,
 - means associated with said conveying means for providing a second signal proportional to the speed of said sheet,
 - means located at each side of said sheet for providing a third signal proportional to the width of said sheet,
 - computer means forming the product of said first, said second, and said third signals and providing a fourth signal proportional to the throughput of said extrusion apparatus,
 - means for generating a fifth signal proportional to a desired value for said throughput, and
 - controller means for adjusting said pump means whenever said fourth signal differs from said fifth signal.
5. Apparatus for increasing the production of an industrial process line, said line receiving a supply of raw material for providing a continuous product having a uniform weight characteristic, said apparatus comprising:
 - means for forming said material into said continuous product,
 - means for feeding said material through said forming means at a controllable rate,
 - means for measuring the mass flow of said product provided by said forming means, and
 - means for adjusting said rate of material feed to said forming means to maintain said product mass flow substantially constant.
6. Apparatus for increasing the production of an industrial process line, said line receiving a supply of a raw material for providing a continuous product having a uniform weight characteristic, said apparatus comprising:
 - means for forming said material into said continuous product,
 - means for feeding said material through said forming means at a controllable rate,
 - means for measuring the mass flow of said product provided by said forming means,
 - means for adjusting said rate of material feed to said forming means to maintain said product mass flow substantially constant, and
 - means for simultaneously maintaining said product weight characteristic substantially constant.
7. Apparatus for increasing the production of an industrial process line, said line receiving a supply of raw material for providing a continuous product having a uniform weight characteristic, said apparatus comprising:
 - means for forming said material into said continuous product,
 - means for feeding said material through said forming means at a controllable rate,

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means for measuring any two of the following quantities:

- (1) the weight per unit area of said formed product,
- (2) the rate of flow of said formed product, or
- (3) the width of said formed product,

means for combining said measurements to provide a signal proportional to the throughput of said formed product, and

means responsive to said throughput signal for controlling the rate of feed of said material through said forming means to maintain said product throughput substantially constant.

8. Apparatus as set forth in claim 7 which further includes means for simultaneously maintaining said product weight per unit area substantially constant.

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WILLIAM J. STEPHENSON, *Primary Examiner.*