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Hart et al.

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[54] SYSTEM AND METHOD FOR OPTIMIZING PROCESSOR OR EQUIPMENT PROFIT

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[52] **U.S. Cl.**.....**235/151.1**, 131/21 B, 235/150.1, 235/151.13, 235/151.33, 250/83.3 D

[51] **Int. Cl.**.....**G06g 7/66**, G05b 13/02

[58] **Field of Search**.....235/150, 150.1, 151, 151.1, 235/151.13, 151.33; 250/83.3 D; 131/21 B

[56] **References Cited**

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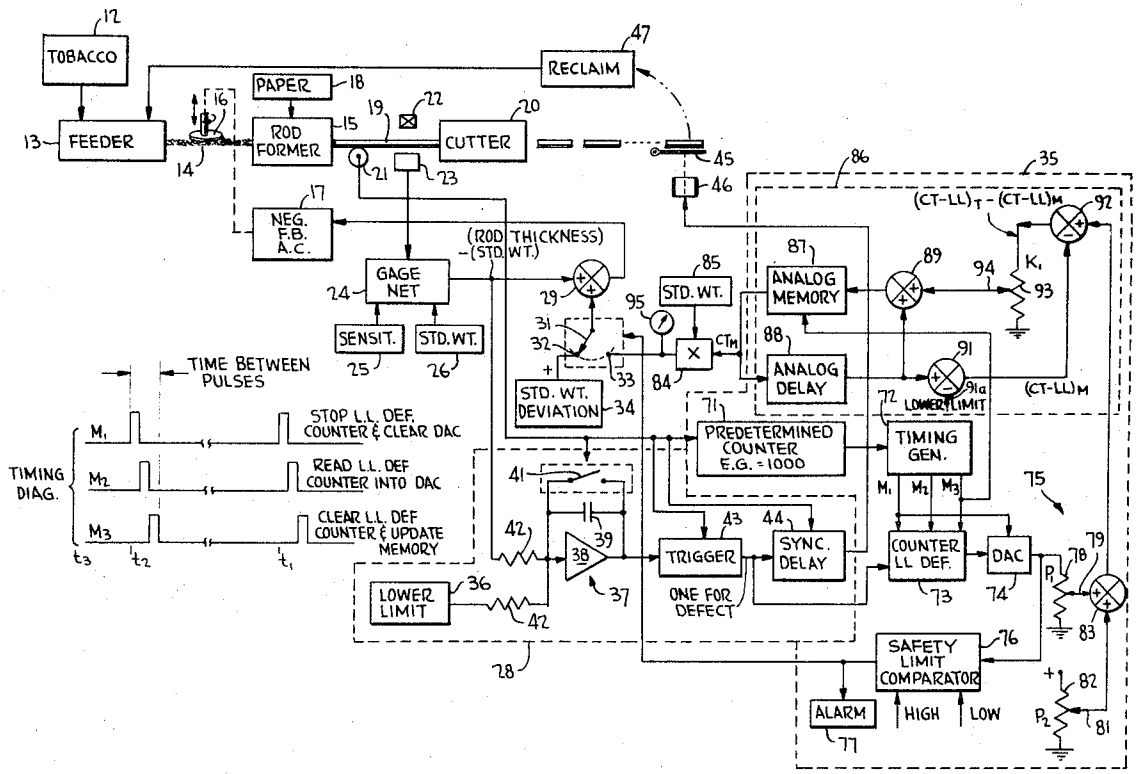
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Attorney—Lowe and King

[57] **ABSTRACT**

In the embodiment specifically described and illustrated, there is disclosed a system and method for maximizing the profit of a tobacco manufacturing process by computing a measure of the process spread, which can be calculated either in response to standard deviation or fraction defective. In response to the calculation of process spread, the average weight of cigarettes manufactured is controlled to maximize profit so that average weight is minimized and variable percentage of the cigarettes weigh less than a limit value. Those cigarettes weighing less than the limit value are identified and the tobacco therein is reused.

41 Claims, 8 Drawing Figures



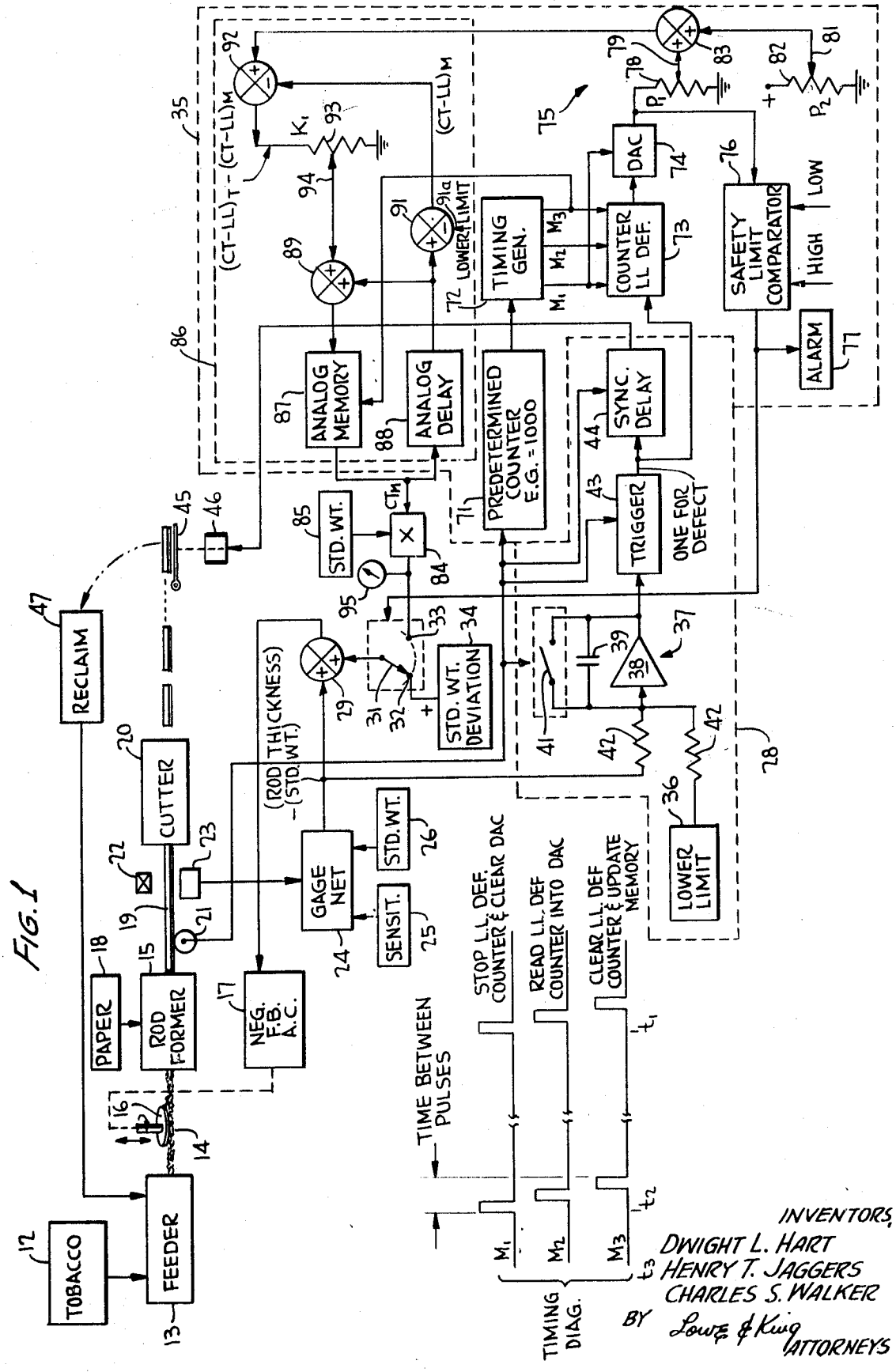


FIG. 1

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FIG. 2

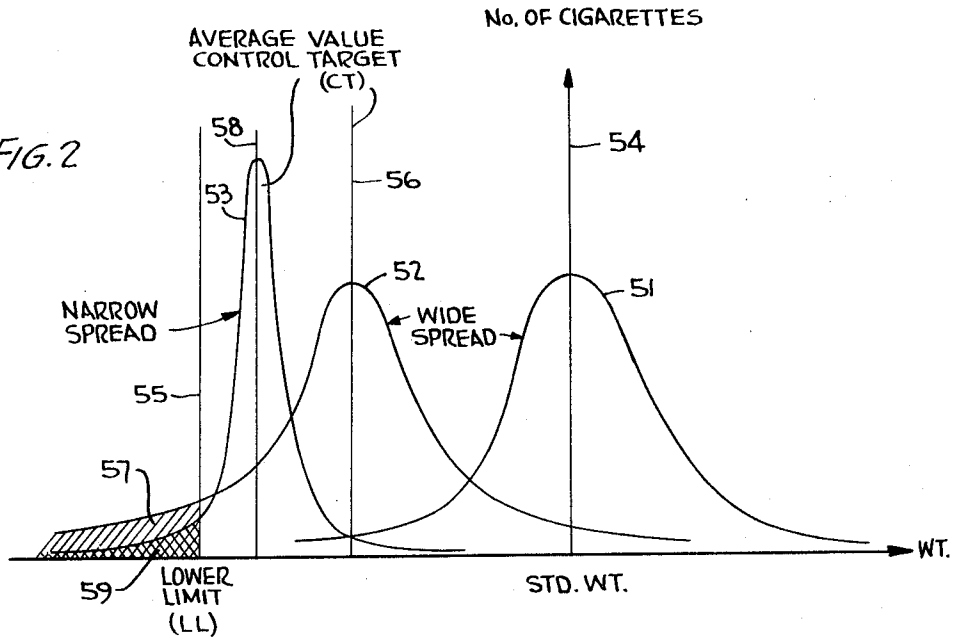
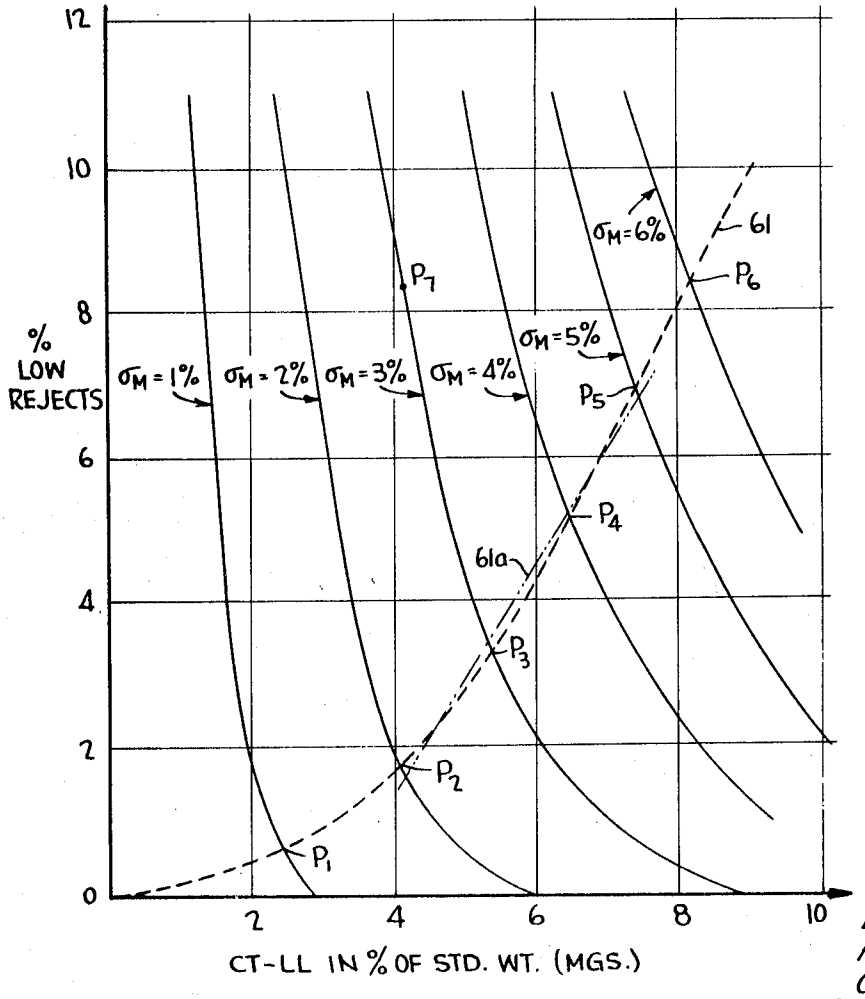


FIG. 3



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FIG. 4

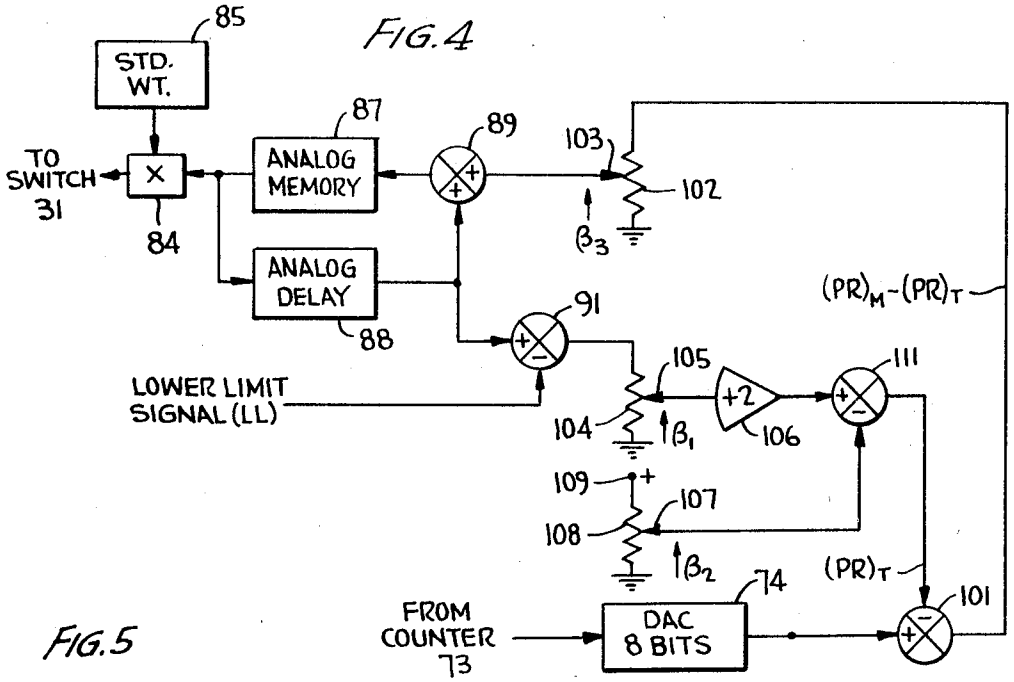
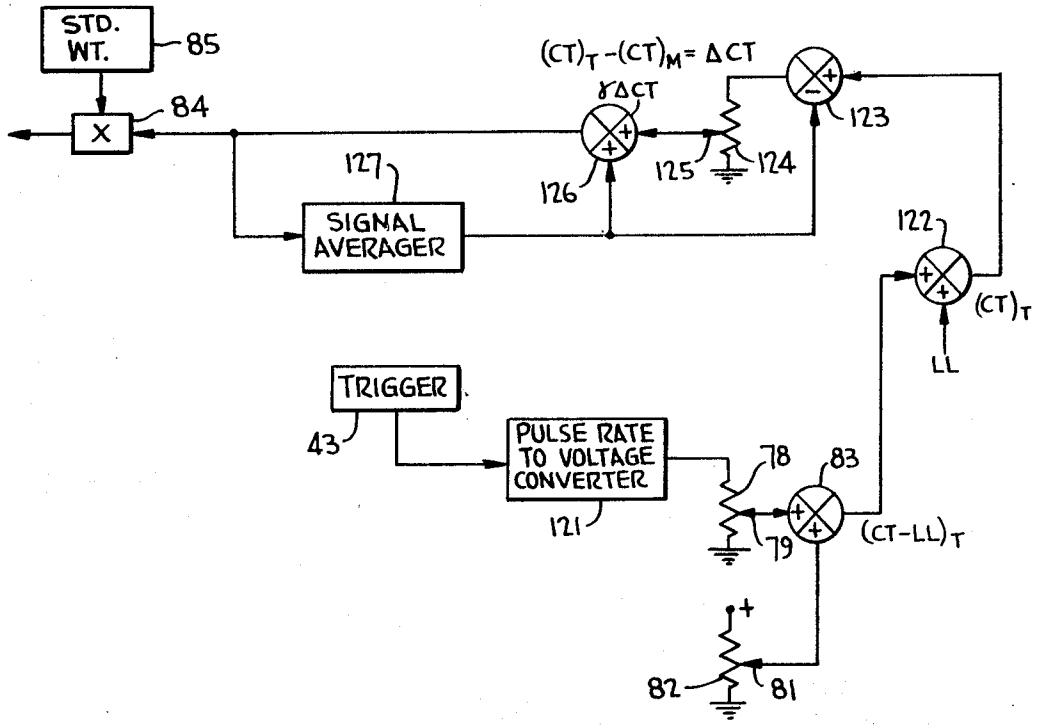


FIG. 5



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FIG. 6

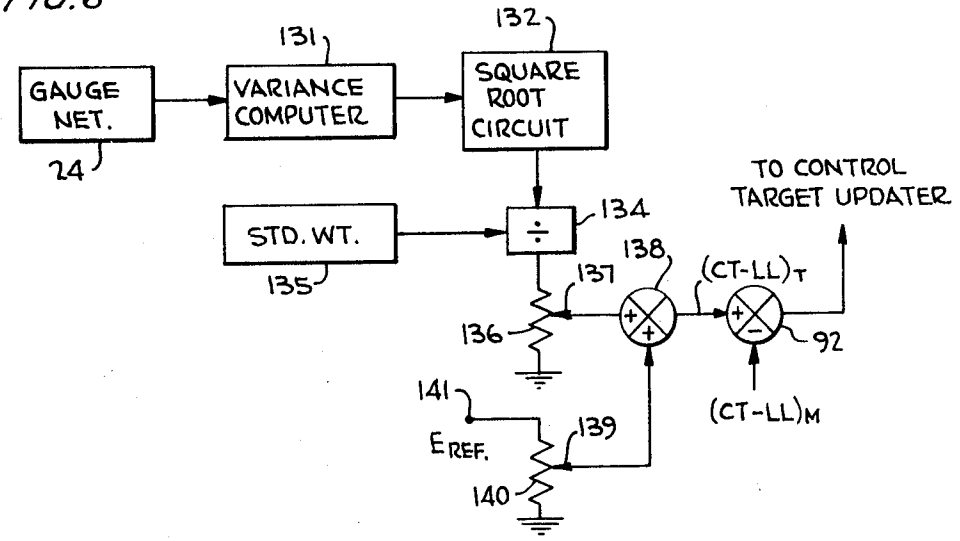
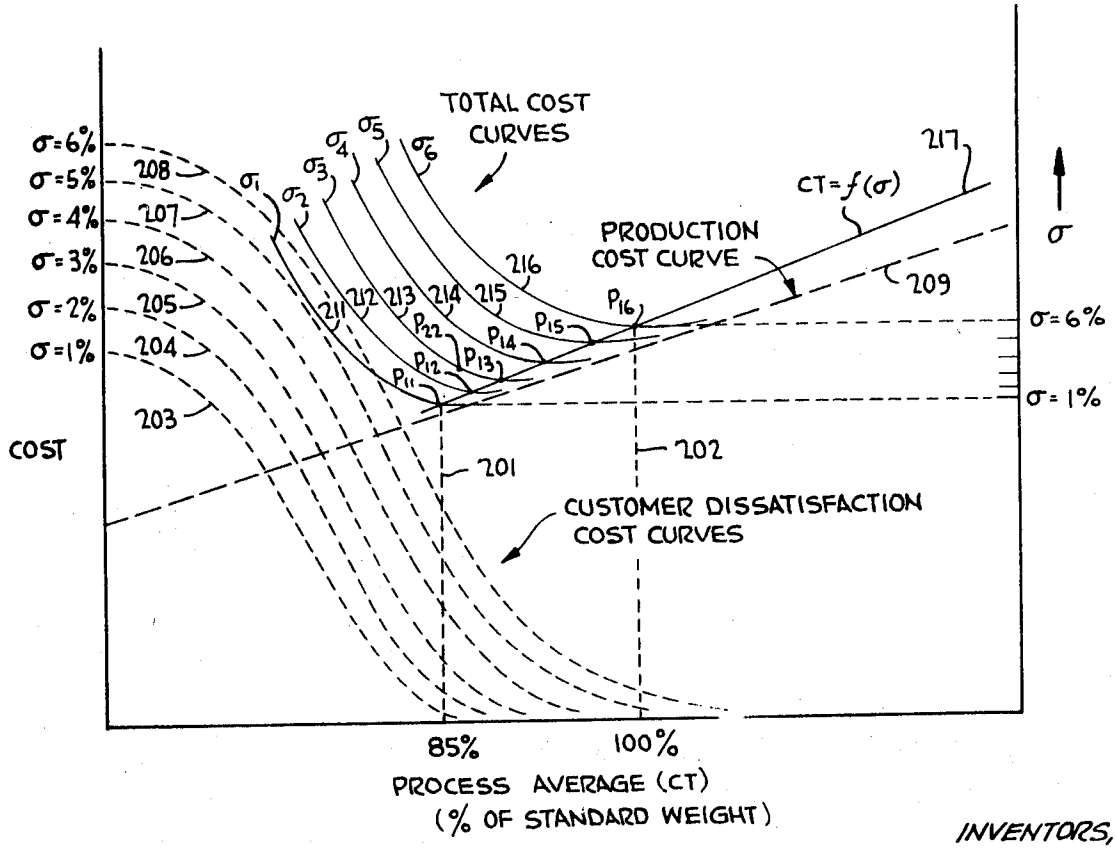
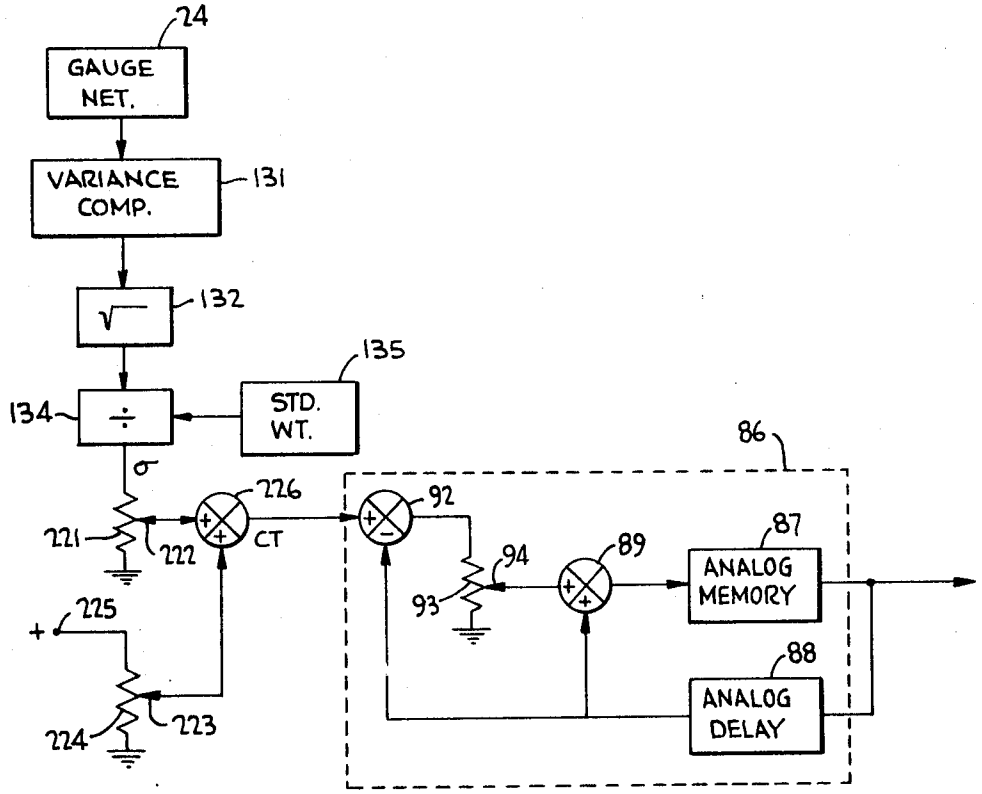


FIG. 7



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FIG. 8



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SYSTEM AND METHOD FOR OPTIMIZING PROCESSOR OR EQUIPMENT PROFIT

The present invention relates generally to process control systems and methods and, more particularly, to a system and method for maximizing the profit of a process in response to a measure of the spread of values of the processor output.

No equipment or processor can produce an output always having the same value, no matter how precisely controlled. Instead, the output of any equipment or processor always covers a range or spread of values. The spread of values is determined by the degree to which the processor or equipment can be controlled and its internal tolerance characteristics, as well as characteristics of inputs. The spread amongst the output values of a processor or equipment can often be determined or closely approximated by a function known as a normal or standard distribution, which defines the well known bell-shaped curve when plotted on an x-y coordinate basis as quantity of output values versus output values per se. The normal distribution bell curve for the output of a processor or equipment is a bell curve having a maximum value for the quantity of output values at the average output value.

Processors and equipment that are rigidly controlled, having tight tolerances and responsive to closely controlled inputs, produce an output having a narrow spread of values, defined by a distribution curve having a relatively sharp peak. In contrast, processors and equipment which are not rigidly controlled, having sloppy tolerances and inputs subject to wide variations, product outputs which generally have a wide range or spread of values. A measure of the spread of values produced by a processor or equipment is a function known as the standard deviation, which is defined as the root-means-square value of the deviations of the output from the average value of the output. If a perfect processor or equipment existed, all of the output thereof would be equal to the mean and the standard deviation of the processor or equipment would equal zero so that the distribution curve would appear as a spike at the average value. Of course, no such perfect processor or equipment exists and the output of any actual system or processor exhibits a spread of values defined by a distribution curve whose characteristics can be determined for the particular process involved by ordinary statistical methods.

It is well known that the standard deviation, σ, or variance, V, of the output of a real time processor is defined as:

$$\sigma^2 = V = \frac{1}{T}\int_0^T [f(t) - \overline{f(t)}]^2\, dt \qquad (1)$$

where:

T = the time interval during which the processor is operating,

$f(t)$ is the variation of the processor output ever the interval T,

$\overline{f(t)}$ = the average value of $f(t)$ during the interval T, and

t = time.

For processors or equipment producing discrete output elements, Equation (1) can be rewritten as:

$$\sigma^2 = V = \frac{1}{N}\sum_{i=1}^{N} (X_i - \bar{X})^2 \qquad (2)$$

where:

N = the number of discrete elements produced by the processor or equipment,

i successively equals every integer between 1 and N,

X_i = the value of the ith output element of the processor, and

$\bar{X}$ = the average value of the N elements produced by the processor.

For processors producing an output that conforms with a known distribution function another measure of the spread or range of values of the processor output can be found by determining the ratio or percentage of the quantity of output values

on either side of a particular value of output sufficiently removed from the average output value. The average value of the processor output generally cannot be utilized as the particular value because if the distribution function is not skewed, for example, the fraction of values relative thereto is always one-half. By selecting the particular value at a point where a product is considered defective, a convenient measure of process spread can be attained by determining the percentage or fraction of the processor or equipment output that is defective. In other words, a measure of the standard deviation or spread of values derived by a processor or equipment can be ascertained by finding the percentage of output having values less than or greater than a limiting value at which the processor or equipment output is considered as being defective.

Mathematically, the fraction defective (F.D.) or 0.01 times reject percentage of the output of a processor or equipment producing N discrete elements can be expressed as:

$$\text{F.D.} = \frac{\sum_{i=1}^{N} f(X_i - X_L)}{N} = 100 \times \text{percentage of rejects} \qquad (3)$$

where:

X_i = the value of the ith output element of the processor,

X_L = a lower limit value, below which values of X_i are considered defective,

i successively assumes every value between 1 and N,

$f(X_i - X_L) = 0$ for $X_i \geq X_L$, and

$f(X_i - X_L) = 1$ for $X_i < X_L$.

If X_L is an upper limit value, above which values of X_i are considered defective, $f(X_i - X_L) = 0$, for $X_i \leq X_L$ and $f(X_i - X_L) = 1$, for $X_i > X_L$.

Typically, processors and equipment have been operated in the past by controlling the processor output to an average value that is sufficiently removed from a limit value, where a defective product is not likely to be produced, on the basis of experience of the processor output spread of values, without reference to the processor current performance. If an input to a processor or equipment is generally subject to relatively wide fluctuations but the processor or equipment can be controlled with a relatively large degree of stability, the prior art has generally set the processor or equipment so that is produces an output having an average value considerably removed from the limit value so that a minimum number of defective output is produced. If the variation of the input to such a processor or equipment should decrease over a relatively long time interval, the average value for the processor output is usually not changed even though a considerably reduced portion of defective output will be derived. By maintaining the processor or equipment output at a constant average value when the processor input variation range decreases the possible profit which the processor or equipment can produce is reduced.

For example, in cigarette manufacturing, cigarettes having a certain minimum weight are considered as acceptable to the consumer. If the cigarette manufacturer can produce cigarettes having an average value as close as possible to the lower acceptable weight limit, he produces a product for which he can have the greatest profit. In an opposite manner, the paper manufacturer desires to produce paper having the largest possible moisture content relative to a limit value at which the paper becomes discolored. Hence, the paper manufacturer attempts to produce a product having the greatest moisture without exceeding an upper limit value. In the prior art, these average values were generally selected on an a priori basis, based upon previous experience without particular regard to the spread of values.

While the prior art has generally relied on experience to set a target value for the average value of a processor or equipment output, there are some teachings that the average value should be controlled in response to a measurement of the

processor output spread of values. In particular, systems have been proposed wherein the average value of a processor output is adjusted so that a predetermined fraction defective or product output is obtained, or so that the average value is removed from a limit value according to a predetermined function of the standard deviation. By maintaining the processor or equipment output at an average value to achieve a predetermined fraction defective, the processor or equipment operates in a more efficient manner to produce a product having a greater profit margin. The greater profit margin arises because the average value of the output can be brought closer to a limit value.

In a theoretically perfect processor or equipment, producing an output having a standard deviation of zero, the average and limit values would coincide to provide maximum profit since this would result in the product having the greatest quantity of acceptable output for the least amount of input. While the limit and average values derived from a theoretical processor should coincide to maximize profits, in a real processor maximum profits are not actually achieved by translating the average value to the limit value. If the limit and average values of a real processor coincide, one-half of the processor or equipment output would be defective, assuming that the processor output follows a normal distribution function. Because of the input material cost necessary to produce the processor or equipment output and the operating cost of the processor or equipment, it is apparent that an output which is one-half defective is intolerable. While in many processors, the output product can be reused, the cost of processor operation and reclaiming defective product preclude coincidence between the processor average value and a limit value for maximum economic profit.

We have found that the average output value of processors or equipment can be controlled relative to a limit value in response to the spread of output values to achieve maximum economic profit. Stated differently, if a processor or equipment produces an output having a first standard deviation, σ_1, to achieve a maximum profit the processor or equipment should be controlled to produce an output having an average value which is removed from the limit value by a certain increment ΔX_1. If, however, the processor or equipment produces an output having a second value of standard deviation, σ_2, maximum economic profit is attained by controlling the processor or equipment so that the average value of its output is removed from the limit value by a second increment, ΔX_2. We have found that a mathematical relationship exists between process spread and deviation of average value from limit value to achieve maximum profit. The mathematical function is different for each processor or equipment, and in fact differs between types of different processors or equipment within a group.

After the average value of the processor or equipment output which maximizes profit as a function of spread has been determined, the processor output average value is varied or controlled by adjusting a target value for the processor output as a deviation from a nominal target or standard average value, determined on an a priori basis. In response to the computed deviation a set point or target for the processor or equipment output is established. Thereby, a target reset relative to the nominal or standard average value for the processor or equipment output is provided. The nominal target and the deviation from target establish a set point or actual target for a negative feedback type controller for the processor or equipment output. Once a stabilized condition has been reached, the negative feedback controller actuates the processor or equipment to produce an output having an average value coinciding with the set point.

More specifically according to the present invention the usage of a costly input quantity such as a raw material input or energy input is to be reduced to such an extent that a significant percentage of the processor output will be found defective on a subsequent inspection. If the average value of the output is controlled to a value closer to the limit value, an economic gain is realized because of the reduction in the amount of the costly input quantity used for a given amount of the product produced. On the other hand, however, if the average output value is so controlled to a value closer to the limit value, for a given process spread a greater percentage of the output will be found to be defective, and an economic loss results.

The economic loss may occur because the manufacturer will not permit the defective portion of the product to be placed on the market, and in this case he incurs the expense of either scrapping the defective product portion or reclaiming the material used therein. In another case the manufacturer may segregate the defective product portion and sell it at a reduced price which is much less than he could obtain for the regularly acceptable product. In still another case the manufacturer may allow the defective product portion to be marketed along with the acceptable produce, realizing that this will result in a predictable amount of customer dissatisfaction which will correspondingly reduce his share of the total consumer market for his product.

The present invention provides methods and means whereby the economic gain achieved by operating closer to the limit and the economic loss occasioned by the defective product portion are mathematically related as a function of process spread so that the maximum economic profit is realized.

While the present invention has general utility, it has particular utility in conjunction with processes and equipment which produce a defective output that can be identified and reused. The applicability of the invention to processes and equipment wherein reclaimable material comprises an output occurs because the output average value can be translated closer to the limit value in these instances. In addition, problems of customer dissatisfaction with defective products in attempting to maximize profit do not occur if outputs having values beyond a limit are separated and reclaimed, rather than being put into the stream of commerce.

In accordance with one specific embodiment of the invention, the profit of a cigarette facility is maximized in response to the spread in the weight of the cigarettes produced thereby. Applicability of the cigarette making facility to the invention as a preferred embodiment results from the ability to readily identify and reclaim cigarettes having a weight less than a predetermined limit value. In addition, it has been found that the relationship between the spread of cigarette weight and the deviation of the average value from the limit value to obtain maximum profit is very nearly a straight line function in the practical operating range for presently existing facilities. Because of this linear relationship, it is a relatively easy procedure or requires little apparatus to relate desired average or target weight to defective cigarettes produced.

It is, accordingly, an object of the present invention to provide a new and improved controller for a processor or equipment whereby maximum profit is achieved for a variable spread of output values and a particular set of quality and manufacturing cost parameters.

Another object of the invention is to provide in a processor for manufacturing a product having defective segments which are readily identifiable and reclaimable, a system and method for deriving an optimum portion of defective product while driving the product average value towards a limit value to maximize processor profit.

A further object of the invention is to provide a new and improved system for and method of setting a target value of a processor or equipment to achieve maximum economic profit and for resetting the target value as changes in output value spreads occur.

Still another object of the invention is to provide a new and improved system and method for maximizing profit of a machine producing a product while maintaining a high degree of customer satisfaction.

A further object of the invention is to provide a new and improved system for and method of controlling a cigarette making machine to maximize profit.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of several specific embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a partly schematic and partly block diagram of a cigarette making machine controlled in accordance with one embodiment of the present invention;

FIG. 2 illustrates standard distribution of cigarette weights to describe a typical operation of the system of FIG. 1;

FIG. 3 is a plot of percent low rejects versus average weight necessary to achieve maximum profit with the system of FIG. 1;

FIGS. 4–6 are block diagrams of alternate embodiments of that portion of the system of FIG. 1 wherein target value for maximum profit is computed;

FIG. 7 is a plot useful in describing still another embodiment of the present invention; and

FIG. 8 is a block diagram which can be employed to implement another embodiment of the invention relying upon the plots of FIG. 7.

The specifically disclosed and illustrated embodiment about to be described is concerned with a cigarette making machine which produces cigarettes having a nominal or standard weight of 1,000 milligrams and a low weight limit of 900 milligrams, below which a particular cigarette is considered to be defective. It is to be understood, however, that the principles of the invention are applicable to other processors or equipment, as well as to the manufacture of cigarettes having different nominal and limit values. In such instances, of course, the profit characteristics are different from those described and illustrated infra.

Reference is now made specifically to FIG. 1 wherein tobacco from an external source **12** is delivered to feeder apparatus **13**. From feeder **13**, tobacco is conveyed on belt **14** in controlled quantities to rod former **15**. The amount of tobacco conveyed between feeder **13** and rod former **15** is controlled in response to an output opening in the feeder and the vertical position of rotary knife **16** above belt **14**. The vertical position of rotating knife **16** is varied by automatic controller **17** having a tachometer feedback, preferably of the type disclosed in United States Pat. No. 3,130,733 to Martin. The controlled amount of tobacco conveyed on belt **14** downstream of knife **16** is combined in rod former **15** with a paper supply from source **18** to produce cigarette rod **19** in a well known manner. Rod **19** is translated by well known means, not shown, to cutter **20**, which produces individual, predetermined length cigarettes which are later sorted and packaged. The velocity of the cigarette rod emerging from former **15** is monitored by tachometer generator **21** which produces one output pulse for each length of rod commensurate with a cigarette of the type being manufactured.

The density properties of rod **19**, as it emerges from former **15**, are monitored with nucleonic gauge comprising penetrating radiation source **22** and ionization detector **23**, positioned on opposite sides of the rod. Ionization detector **23** derives a DC output signal voltage inversely proportional in amplitude to the density of rod **19**. The output signal of detector **23** is fed to gauge network **24** of a well-known type, as described in U.S. Pat. Re. 25,476 to Radley et al. As described in the Radley et al. patent, gauge network **24** includes sensitivity setting **25** and standard weight setting **26**. For a particular value of the standard weight of the cigarettes being manufactured, settings **25** and **26** are adjusted so that gauge network **24** derives a DC output voltage having a linear relationship to the density of rod **19** as the rod passes between source **22** and detector **23**. If the density of rod **19** as it passes by the gauging station including source **22** is such that a cigarette has a weight equal to that of standard weight setting **26**, the output of gauge network **24** is zero. For increasing and decreasing densities of rod **19**, the output voltage of network **24** goes positive and negative, respectively, in a manner linearly related to the weight of the cigarettes which are being produced. The output of gauge network **24** is thereby an analog signal linearly related to the weight of a unit length of cigarette rod equal to one cigarette minus a target value established by the nominal standard weight for a cigarette determined by setting **26**.

The output of network **24** is fed in parallel to reject classifying network **28** and linear combining or summing node **29**. The other input to summing node **29** is derived from toggle switch **31**, selectively connected to contacts **32** and **33**. With switch **31** set on contact **32**, as illustrated, a positive voltage indicative of a manually set deviation from standard weight signal is fed into summing node **29**. With switch **31** engaging contact **33** a DC signal derived from an automatic control network **35**, described infra, is fed to one of the inputs of summing network **29**. Standard weight deviation source **34** and network **35** are set or automatically derive a signal, respectively, to change the nominal target value of standard weight setting **26** so that the economic profit which can be derived from the cigarette making apparatus can be maximized. The signal supplied to summing node **29** by switch **31** can be thought of as a target reset for the nominal target of standard weight setting **26**. Summing node **29** can thereby be thought of as a deviation of cigarette weight from a target determined by standard weight setting **26** and the signal on contact **31**.

In operation, with standard weight setting **26** being set, for example, to a value commensurate with a cigarette weight of 1,000 milligrams and standard weight deviation setting **34** being set to a value commensurate with −50 milligrams, the cigarette making apparatus produces cigarettes having an average weight of 950 milligrams. If the weight of a cigarette length in the rod should be, for example, 960 milligrams, gauge network **24** derives an output signal having a negative value and an amplitude commensurate with −40 milligrams, the deviation between the 960 milligram cigarette detected by the gauging station and the 1,000 milligram setting of input **26** to network **24**. The −40 milligram signal derived by gauging network **24** is combined with a +50 milligram signal fed into source **34**, whereby summing network **29** derives an output signal indicating that the cigarette rod has a weight of 10 milligrams in excess of the desired setting established by sources **26** and **34**. The signal derived by summer **29** is fed to automatic controller **17** which drives knife **16** downwardly by an appropriate amount until the output of summing network **29** is zero and the desired average value for a cigarette length of the rod has been reached.

To determine if a particular cigarette length is defective, as determined by the weight thereof being less than a predetermined value or lower limit, the output of gauge network **24** is fed to reject identification network **28**. Network **28** includes a source of DC voltage **36** having an amplitude commensurate with the rod density which produces cigarettes having a weight equal to the lower limit. For a typical standard weight setting **26**, the potential of source **36** is commensurate with a density which produces cigarettes having a weight 100 milligrams removed from the standard weight. Hence, a lower limit of 900 milligrams is established for standard weights of 1,000 milligrams, while a lower limit of 1,000 milligrams would be set if the standard weight were 1,100 milligrams. Since the output of gauge network **24** is a bipolarity signal having a zero value in response to coincidence between the weight of cigarettes in rod **19** being coincident with the standard weight, rather than in absolute terms of weight, there is no need to change the amplitude of source **36** if the standard weight of a cigarette should be changed.

The variable amplitude density signal derived from gauge **24** is compared with density signals for lower limit as derived from source **36** in integrator **37** for a time period equal to the time required for one cigarette length of rod **19** to pass through the gauging station comprising source **22**. If the weight of the rod over a one cigarette length should exceed the lower limit of 900 milligrams, the output of integrator **37** is negative, while a positive voltage is derived if the cigarette weight is less than the lower limit. To derive these bipolarity signals, integrator **37** includes a high-gain, polarity-reversing

operational amplifier 38. Bridging the input and output terminals of amplifier 38 is capacitor 39, discharged instantaneously once during each cigarette processing time in response to switch 41 being closed by each output pulse of tachometer 21. The input terminal of amplifier 38 is responsive to the output of gauge network 24, as well as the DC potential derived by source 36, as coupled through summing resistors 42. Thereby, if the average density of a particular cigarette passing the gauge station including source 22 is less than or greater than the lower limit density established by DC source 36, positive and negative voltages are respectively derived from amplifier 38 immediately prior to closure of switch 41.

The output voltage polarity of amplifier 38 immediately prior to each closing of switch 41 is sensed by trigger network 43, which is of a well-known type. To this end, trigger network 43 is responsive to output pulses derived by tachometer generator 21 so that the output of amplifier 38 is fed thereto only immediately prior to each closure of switch 41. In response to positive and negative voltages being coupled to trigger circuit 43, binary one and zero signals are respectively derived thereby. Thereby, for each defective cigarette, having a weight less than the lower limit offset established by source 36, circuit 43 derives a binary one output.

The binary one and zero signals derived by trigger circuit 43 are fed to synchronous delay 44, preferably of the shift register type. Binary one signals loaded into the initial stage of the shift register comprising synchronous delay 44 are propagated to higher order stages of the shift register in synchronism with the movement of the cigarette rod in response to pulses supplied to the delay element by tachometer generator 21. The number of stages included in the shift register comprising delay 44 is such that a particular segment of rod 19 as it passes within the gauging station 22 is positioned at reject kicker 45, downstream of cutter 20, at the same time that an output is derived by the delay element. Thereby, if a defective cigarette passes through the gauge station including source 22, a binary one output value derived by said element 44 as that region of rod 19 passes above reject kicker 45. The output of synchronous delay 44 is coupled to solenoid 46 which is energized only by binary one outputs of the delay to energize kicker 45. thereof,

Those defective cigarettes which are separated and identified from cigarettes weighing more than the reject limit are fed to a reclamation processor 47. Reclamation processor 47 removes the tobacco from the paper of the rejected cigarette and supplies this tobacco back to feeder 13 so that it can be reused in the process.

The apparatus and process specifically described to this point are well known to those skilled in the art and generally form no part of the present invention.

Because of the inability of the cigarette processing machinery described to produce cigarettes all having the same weight, there is a spread of weights amongst the cigarettes produced by the processor of FIG. 1. The spread of weights follows generally the normal distribution curve, of the type illustrated by curves 51–53 in FIG. 2, where the number of cigarettes having a particular weight is plotted against weight. Curves 51 and 52 represent equal relatively wide distributions of cigarette weights, i.e., curves 51 and 52 have the same relatively large standard deviation, while curve 53 represents a relatively narrow spread of cigarette weights. The wide spreads of curves 51 and 52 generally result from tobacco in source 12 having a relatively inhomogeneous density and may be attributed to loose tolerances in the mechanism comprising the tobacco manufacturing apparatus. A narrow spread, as illustrated by curve 53, occurs if the tobacco in source 12 has a consistent density and each of the mechanical elements in the tobacco manufacturing apparatus is tightly adjusted to close tolerances.

Curve 51 illustrates the distribution of cigarette quantity for the cigarette manufacturing apparatus producing cigarettes to a target equal to that of the standard weight setting 26 as occurs in response to a zero offset being coupled to summing node 29 via switch 31. Even for the wide spread of values indicated by curve 51, having an average value coincident with the cigarette standard weight (indicated by vertical line 54), virtually none of the cigarettes weighs less than the lower limit, indicated by vertical line 55. Thereby, with the distribution of curve 51, a processor target equal to the standard weight setting results in cigarettes having an average weight considerably greater than the lower limit value which a consumer is willing to accept and virtually no cigarettes having a weight less than a lower limit, indicated by vertical line 55. The tobacco manufacturer is able to attain a greater profit if he changes the average cigarette weight so that is is closer to lower limit line 55 even though a greater portion of the cigarettes are defective because they have weights less than the lower limit value. Hence, to attain a greater profit margin with a spread indicated by curve 51, the average value of the cigarettes produced is translated to a lower value. The lower average value merely causes a translation of curve 51 to the left, without changing the shape thereof, so that the greatest number of cigarettes have a weight indicated by vertical line 56, which coincides with the average value of curve 52. Shifting curve 51 from an average value commensurate with the standard weight line 54 to line 56 results in a greater percentage and amount of the cigarettes having a weight less than lower limit weight 55. The amount of defective weight cigarettes is the area to the left of line 55 and under curve 52, indicated by crosshatched area 57.

If the tobacco manufacturing equipment and process produce cigarettes having a very narrow spread of values, as indicated by curve 53, even greater savings and higher profits can be achieved. In particular, with the narrow spread illustrated by curve 53, for maximum profit the average value of the cigarettes produced is translated extremely close to lower limit weight 55, to the weight indicated by vertical line 58. The amount of defective cigarettes for the narrow distribution curve 53, the cross-hatched area 59 under curve 53 and to the left of line 55, in terms of percentages is less than for the wide spread of curve 52. For narrow cigarette distribution spreads, maximum profit is attained for a lower fraction defective than for wide cigarette distribution spreads. In other words, in cigarette manufacturing, the greater or wider the distribution of values the more defective cigarettes should be made and reclaimed to maximize profit. The realization that a lower fraction defective for a narrow spread than for a wide spread produces maximum profit is a deviation from past thinking and certain prior art systems wherein it was attempted to maintain fraction defective constant, or by the same token to maintain the average value removed from a limit value by a multiple of standard deviation, σ.

The relationship we have found to exist between fraction defective and the deviation between the average value or control target from the lower limit to attain maximum profit in a tobacco processor of the type illustrated in FIG. 1 is shown by curve 61 of FIG. 3. To derive curve 61, there are first plotted the series of curves labeled σ_M=1%, σ_M=2%, etc. These curves show the percent of the total production (percent low rejects) falling below a lower limit LL as a function of the separation CT–LL of the process mean (average) and the lower limit for the assumed σ values of 1 percent, 2 percent etc. Since the typical cigarette making process has been found to follow a normal distribution, the standard deviation σ is normalized to the process mean and the percentage of low rejects are then obtained directly from statistical tables found in many available handbooks.

It is understood that when the automatic controller 17 is set to operate with a given control target CT, the controller will automatically regulate the process so that the process mean will correspond to the control target CT. Referring to FIG. 2, the selection of a control target CT which is less than the standard weight results in a nominal saving in tobacco cost, for a predetermined number of cigarettes produced, which saving can readily be computed for a number of arbitrarily selected values for CT. For each selected CT value, there is a cor-

responding value for CT–LL, and a further corresponding value of percent low rejects which can be read from the appropriate one of the curves labeled σ_M=1 percent, σ_M=2 percent, etc. The cost of producing this percentage of low rejects is then computed for each value of CT, and the reject cost is subtracted from the nominal saving to determine the net saving.

It is found that as CT is reduced from the standard weight, thus decreasing CT–LL, the net saving increases up to a certain point. Beyond this point, however, as the percent rejects increase rapidly, it is found that the net saving begins to decrease as CT is further reduced. The value of CT–LL which produces the maximum saving can thus be determined and used to locate a point P on the appropriate one of the curves σ_M=1 percent, σ_M=2 percent, etc. The procedure is repeated for each of the other assumed values of σ, to locate all of the points P_1 to P_6 shown in FIG. 3. Curve **61** is a smooth curve drawn through these points, and is the locus for the most economic operation of the machine to maximize profit.

It is understood that other processes to which the invention can be applied may not follow a normal distribution, and unfamiliar processes must be statistically analyzed before the foregoing procedure is adopted in toto. If the process does not follow a normal distribution, the use of a handbook tables based thereon may not be appropriate, and the percent low reject figures must be computed from the actual distribution functions determined experimentally according to well known statistical procedures.

From FIG. 3, it is to be noted that in the region of practicality, where standard deviation, in terms of percentage of standard weight, is between 2 and 5 percent, curve **61** can be closely approximated as a straight line function **61***a* defined by:

$$(CT–LL)=3.1\%+0.658\ (\%\ \text{rejects}) \qquad (4)$$

where:

(CT–LL) = the deviation of the desired target from the lower limit in percent of standard weight,

3.1% = a constant, and

(percent rejects) is commensurate with fraction defective as defined by Equation (3) supra.

To determine the fraction of or percent defective input for Equation (4) and derive a target offset signal indicative of the amount by which the average value of the cigarettes should be changed to optimize or maximize profit, network **35** of FIG. 1 is provided. property, of by a decreases

To determine percent or fraction defective, which is commensurate with the ratio of the area of crosshatched region **57** to the total area under the curve **52**, for example, the number of defective cigarettes in a predetermined number of manufactured cigarettes is found. To derive a signal indicating when the cigarette maker has processed a predetermined number of cigarettes, predetermined counter **71** is provided and connected to be responsive to the output of tachometer generator **21**. Counter **71** is set to any suitable number, such as 1,000, so that a binary one output signal is generated thereby in response to 1,000 cigarettes being processed by the cigarette making apparatus. The binary one output signal derived by counter **71** is supplied to timing generator **72** which generates three out of phase but of like frequency pulses, designed by M1, M2 and M3. Pulses M1, M2 and M3, occurring in mutually exclusive time periods in the order named, are derived by generator **72** so that the leading edge of the first and the trailing edge of the latter coincide substantially with the leading and trailing edges of each one thousandth pulse derived by tachometer generator **21**.

The M1 output pulse is fed to counter **73**, having a count advance input responsive to the binary one defect indicating signals of trigger network **43**. The M1 pulses are also fed to digital-to-analog converter **74**, having a signal input responsive to the count stored in counter **73** during a readout operation. In response to the M1 pulses, the counting action of counter **73** is terminated and the output of digital-to-analog converter **74** is cleared to zero. Thereby, after 1,000 pulses have been generated by tachometer generator **21**, counter **73** stores a count indicative of the number of defective cigarettes manufactured during the previous 1,000 cigarettes produced and any previous signal stored in digital-to-analog converter is removed.

In response to the M2 output pulse of timing generator **72**, counter **73** is activated so that the count stored therein is read out and coupled to digital-to-analog converter **74**. Converter **74** responds to the output of counter **73** and generates a DC analog voltage level commensurate therewith. The analog voltage level generated by converter **74** is maintained until the next M1 pulse is derived by timing generator **72**, i.e., while the next 1,000 cigarettes are being processed.

In response to the M3 output pulse of timing generator **72**, the count stored in counter **73** is cleared and a zero state is maintained therein. In response to succeeding binary one defective indicating output signals of trigger network **43**, the count of counter **73** is advanced and the process continues. In the manner described, it is believed obvious as to how digital-to-analog converter **74** derives an analog output indicative of the fraction or percent defective of cigarettes having a weight less than the lower limit.

The fraction defective output signal of digital-to-analog converter is applied in parallel to safety limit comparator **76** and network **75** which automatically performs the initial computations necessary to produce a change in the average cigarette weight to achieve maximum profits, i.e., optimum target and percent rejects, for the particular spread under the specified conditions. Safety limit comparator **76** derives a binary zero output signal as long as the voltage generated by converter **74** is commensurate with a fraction defective within prescribed low and high boundaries, typically selected as 1.5 and 7 percent fraction defective, respectively. If the output voltage of converter **74**, except during the resetting operation thereof, is outside of the high or low limits, comparator **76** derives a binary one signal level that actuates alarm **77**, which may be of the aural or visual type, and overrides the position of contact **31** to drive the contact into engagement with terminal **322**. Thereby, if the weight distribution exceeds predetermined high or low limits an operator is appraised of that factor and can manually control the cigarette processor target. High and low limits for process fraction defective are included to provide for malfunctioning of both the tobacco system equipment and the gauging and calculating apparatus, events which can be detected in response to the defective percentage being outside of limits defined by 1.5 and 7.5 percent.

To compute the deviation of desired target from lower limit as a percentage of standard weight (CT–LL) percent that results in maximum profit for a particular spread of output values, as measured by percent reject, in accordance with Equation (4), the output of digital-to-analog converter **74** is applied across the input terminals of potentiometer **78**, having a slider **79** adjusted to a scale factor of 0.658. The variable DC product voltage at slider **79** is combined with a constant voltage at slider **81** of potentiometer **82**, having a value commensurate with the constant **3.1** percent, dictated by Equation (4). The voltages derived from taps **79–81** are linearly combined in summing network **83**, the output voltage of which is a function of the deviation of desired target from lower limit, in percent of standard weight.

The target deviation from lower limit calculated for the 1,000 cigarettes processed during the sampling period between the two immediately preceding timing pulses t_1 and t_2 derived by generator **72**, is compared with the deviation determined during the previous sampling period, defined by timing pulses t_2 and t_3, to indicate the amount by which the target should be adjusted. To these ends, network **86** is provided.

Network **86**, in addition to being responsive to the current target deviation indicating output signal of summing network **83** during the period between t_1 and t_2, includes a feedback network responsive to the previously computed optimum target during the period between t_2 and t_3 and an input indicative of lower weight limit, in terms of percentage deviation from

standard weight. The output signal of network **86**, derived from sample and hold analog memory **87**, is fed through analog delay **88** to summing network **89** and the minuend input of subtracting network **91**. The subtrahend input **91***a* of subtraction network **91** is responsive to a DC voltage input having a value commensurate with the lower weight limit, in terms of percent deviation from standard weight. The output of subtraction network **91** is a DC voltage commensurate with the deviation from the lower limit of the previously calculated target offset from standard value in percent standard value, $(CT-LL)_M$ necessary to achieve maximum profit. The previous target deviation signal relative to lower limit output of subtraction network **91** is compared with the presently computed signal indicative of deviation from lower limit $(CT-LL)_T$ in subtraction network **92**, having minuend and subtrahend inputs respectively responsive to the output signals of adder **83** and subtracter **91**.

The difference signal derived from subtraction network **92** is applied across the input terminals of potentiometer **93**, having a slider **94** adjusted so that the target value cannot be translated to the full degree indicated by the output signal of subtracter **92**. Typically, the setting of slider inserts a 0.25 gain factor on the output of subtracter **92**. Thereby, stability of the processor is maintained despite changes in the process spread and target overshoot and oscillation is prevented. The signal on tap **94** is added to the output of analog delay **88** in summing network **89**, the output of which feeds analog memory **87**.

Analog memory **87** is of the sample and hold type, including an input responsive to the M3 pulse derived by timing generator **72**. Thereby, once every 1,000 cigarettes, the signal stored in analog memory **87** is updated and the memory derives a constant output voltage for the next 1,000 cigarettes being manufactured. The effect of analog delay element **88** is such as to decouple the transient, step nature of analog memory **87** from the input to subtracters **89** and **91** while memory **87** is responsive to the output of the former subtracter.

To convert the percent of standard weight output of memory **87** into a signal indicative of deviation in absolute terms, multiplier **84** is provided. Multiplier **84** responds to the output of memory **87** and the DC voltage of source **85**, which is set by a ganged potentiometer arrangement simultaneously with the setting of the standard weight input **26** of gauge network **24**. The output of multiplication network **84** is thereby a DC analog voltage commensurate with the deviation of desired target from standard weight, in terms of cigarette weight. To monitor the deviation from standard weight signal derived by multiplier **84**, DC voltmeter **95** is provided.

To provide a better understanding as to the manner by which the system of the present invention functions to adjust the target value of the cigarette processor shown, several examples will be considered. In each of the examples, it will be assumed that the standard cigarette weight is 1,000 milligrams, the lower limit equals 900 milligrams, a value 10 percent less than standard weight, contact **31** engages terminal **33** and the process is governed by the set of curves shown by FIG. **3**.

The system is initially presumed to have been in operation and stabilized at a standard deviation, σ, of 2 percent of standard weight (i.e., 20 milligrams) which results in a fraction defective of 1.6 percent and a deviation of desired target from lower limit of 4.2 percent of standard weight as appears from the point labeled P_2 in FIG. **3**. The 4.2 percent output of summing circuit **83** of network **75** is translated by network **86** into a deviation from standard weight of 5.8 percent of standard weight, the output of analog memory **87** that is fed to multiplier **84** that drives terminal **33** with a voltage indicative of 58 milligrams.

Let it now be assumed that for the 1,000 cigarettes just processed, the standard deviation is again 2 percent so that the fraction defective output of digital-to-analog converter is 1.6 percent. The 1.6 percent fraction defective output of digital-to-analog converter **74** is translated by network **75** into a voltage commensurate with 4.2 percent of standard weight. The output of analog memory **87**, indicative of a 5.8 percent deviation from the standard weight to achieve maximum profit for the preceding 1,000 cigarettes, is subtracted from the 10 percent lower weight limit input signal to subtraction network **91**. The resulting 4.2 percent output signal of subtracter **91** is compared with the 4.2 percent output signal of subtracter **83** in subtractor **92**, the output of which is thereby 0 voltage. Since the output voltage of subtracter **92** is 0, the output of analog memory **87** does not deviate before and after the M3 pulse is generated by timing generator **72** and the target value for the next 1,000 cigarettes produced is the standard weight setting input **26** for gauge network **24** minus 58 milligrams, or 942 milligrams.

For 1,000 cigarettes produced during the period considered, 942,000 milligrams of tobacco are used at the beginning of the process. Of the 1,000 cigarettes produced, 18 weight less than 900 milligrams so that the amount of tobacco fed back from reject kicker **45** through reclamation station **47** to tobacco feeder **13** is less than 16,200 milligrams. Thereby, the total amount of tobacco required to make the 982 cigarettes is 925,800 milligrams.

Let it now be assumed that due to some property of the input tobacco or the tobacco processing equipment, the standard deviation of the cigarettes produced suddenly jumps to three percent, whereby the output of digital-to-analog converter **74** jumps vertically in FIG. **3** to point P_7 to a potential commensurate with a percent defective of 8.4. The 8.4 percent output of digital-to-analog converter **74** is converted into a deviation from lower limit for average value of 8.6 percent by network **75**. The 8.6 percent output voltage of network **75** is compared in subtraction network **92** with the previous desired average value deviation from lower limit of 4.2 percent, as derived from subtracter **91**. The resulting +4.4 percent output signal of subtracter **92** is multiplied by a constant factor, generally on the order of 0.25, in potentiometer **93**. The resulting voltage at tap **94** of potentiometer **93**, commensurate with 1.1 percent, is added to the −5.8 percent indicating output signal of analog delay circuit **88** in addition network **89**. In response to the next M3 pulse derived by generator **72**, the 4.7 percent output voltage of network **89** is fed to analog memory **87**, converted to a target deviation weight of 47 milligrams by multiplier **84**, the output of which is coupled to summing node **29** via switch contact **31**.

Assuming that the standard deviation remains at a value of **3** percent, the output of analog memory **87** is translated along the σ=3 percent curve finally to attain a deviation of target from standard value commensurate with −4.6 percent whereby the actual target and average weight of cigarettes produced is 954 milligrams. For 1,000 cigarettes made by rod former **15** and sliced by cutter **20**, 954,000 milligrams must be supplied to feeder **13** by tobacco source **12**. In accordance with FIG. **2**, of these 1,000 cigarettes, 33⅓ cigarettes weigh less than 900 milligrams so that the amount of tobacco fed to feeder **13** by reclaimer **47** is less than 30,150 milligrams. Thereby, the amount of tobacco required to make the 966.5 cigarettes which are considered as satisfactory is 923,850 milligrams. By comparing the figures for steady state operation at standard deviations of σ=2 percent and 3 percent, it is seen that the average value for the lower standard deviation is closer to the lower limit and that the number of defective cigarettes is greater for the wider process spread.

Reference is now made to FIG. **4** of the drawings wherein a modified form of the portion of network **35**, FIG. **1**, for computing the target deviation, is illustrated. In the system according to FIG. **4**, circuit elements **101–109** and **111** replace elements **78**, **79**, **81–83** and **92–94** of FIG. **1**. Other elements corresponding to those shown in FIG. **1** bear the same reference numerals, and in particular those elements shown in FIG. **4** which receive input signals or provide output signals are the same elements shown in FIG. **1**. In the embodiment of FIG. **4**, the percent reject output signal of digital-to-analog converter **74** is compared with a previous percent reject signal, as

derived from the input of multiplier **84**, to derive a percent reject deviation signal. The deviation signal is modified by a parameter related to the economic profit performance of the cigarette manufacturing equipment to control the reset target, the slope of the curve of FIG. **3**. To determine the percent rejects and enable a deviation from past values to be determined, Equation (4) is solved for percent rejects and can thereby be written as:

$$(\%\ \text{rejects})=1.52(CT-LL)\%-4.72\% \quad (5).$$

In order to solve Equation (5), two cigarette producing machine parameters are involved, namely 1.52 and 4.72 percent. Since the slope of the curve of FIG. **3** as well as the constants of Equation (5) are necessary to determine the optimum average value in the FIG. **4** system, in contrast to only a pair of parameters for the system of FIG. **1**, the latter embodiment is deemed slightly preferable to that of the former.

Considering the specific apparatus of FIG. **4**, the DC analog output voltage of converter **74** indicative of percent rejects between t_1 and t_2 is compared in subtraction network **101** with a feedback signal indicative of the percent rejects during the 1,000 cigarette processing period between t_2 and t_3. The feedback signal applied to subtracter **101**, derived in a manner described infra, is applied to the subtrahend input, while the minuend input of the subtracter is responsive to the output of digital-to-analog converter **74**. The output of subtracter **101**, indicative of the deviation between the past and present percent reject signals, is applied between the input terminals of potentiometer **102**, having a slider **103**.

By reference to FIG. **3**, the value of the gain setting for slider **103** which gives a full correction to the proper new value on the straight line operating locus **61***a* is found to be 0.18. Then in order to prevent overshoot and assure stability to the system in response to changes in the percent rejects between 1,000 cigarette samples, the slope factor in the setting of slider **103** is modified appropriately, being typically reduced by a factor of 0.9. For the particular tobacco making facility having a performance dictated by FIG. **3**, the setting of slider **103** thereby inserts a gain factor of 0.16 in the deviation output voltage of subtraction network **101**. The voltage at the slider **103** of potentiometer **102** is thereby a measure of the percentage change in the deviation between adjacent 1,000 cigarette processing periods for the desired target relative to the lower limit, the same factor as is derived from slider **94** of potentiometer **93** in FIG. **1**.

The output voltage at slider **103** is processed in analog adder **89**, analog memory **87** and multiplier **84** in exactly the same manner as described supra with regard to FIG. **1** to derive an input signal to summing node **29** indicative of the target offset from the standard value. In addition, the output of analog memory **87** is fed back through analog delay element **88** to the input of adder **89** and subtracter **91** in the same manner as described supra. The output of subtracter **91** is thereby a signal indicative of the deviation of the desired target from the lower limit in terms of percentage of the standard value.

The output of subtracter **91** is applied to an analog computer network designed to solve Equation (5), supra. In particular, the desired target deviation from lower limit for the previous 1,000 cigarette processing period, as derived from the output of subtracter **91**, is multiplied by one-half of the 1.52 factor of Equation (5) in potentiometer **104**, having a slider **105** which is appropriately positioned. The voltage at slider **105** is multiplied by a factor of 2 in noninverting operational amplifier **106**, the output of which is a DC voltage directly proportional to 1.52(CT–LL) percent. The output of amplifier **106** is added to the DC voltage developed at slider **107** of potentiometer **108**, having a DC reference voltage applied to its terminal **109**. For the specific situation of Equation (5), slider **107** is set so that the voltage derived thereby is commensurate with 4.72 percent. The voltages at the output of amplifier **106** and at slider **107** are respectively applied to the minuend and subtrahend inputs of subtracter **111**, which derives a DC output voltage directly proportional to the percent rejects of the previous 1,000 cigarette processing period, between timing pulses t_2 and t_3.

Reference is now made to FIG. **5** of the drawings wherein there is illustrated still another embodiment of the system of FIG. **1**. In the FIG. **5** embodiment, the basic philosophy involved in determining the desired target from the lower limit is the same as that employed in FIG. **1**. In the system of FIG. **5**, however, counter **73** and digital-to-analog converter **74** are replaced with pulse rate to voltage converter **121**, whereby the fixed sampling period of the FIG. **1** embodiment is not employed. Also, the network **86** of FIG. **1** is replaced according to FIG. **5** with circuit elements **122–127**. Those elements shown in FIG. **5** which receive input signals or provide output signals are the same elements shown in FIG. **1**.

Referring now particularly to the embodiment of FIG. **5**, the output of trigger network **43** is applied directly to pulse rate to voltage converter **12** which linearly converts the rate at which pulses are derived by the trigger network into a DC analog voltage. The output of converter **121** is directly proportional to the frequency with which binary one pulses are applied thereto by trigger circuit **43**, so that as the number of pulses per unit time being fed to the converter increases and decreases, the output voltage thereof similarly increases and decreases. The DC voltage derived by converter **121** is fed to potentiometer **78**, the output of which is combined in summing network **83** with the voltage at slider **81** of potentiometer **82**, in exactly the same manner as described in conjunction with FIG. **1** for generating an indication of deviation of desired target from lower limit.

The DC output voltage of adding network **83** is added to a DC voltage proportional to lower limit, in terms of percent deviation from the standard value, in summing network **122**, having an output which is a function of desired target, in terms of deviation from standard weight. The desired target weight functional signal, derived from summing network **122**, is compared with an averaged past value of desired target in subtraction network **123**, the output of which is thereby a function of the difference between target deviation from standard value presently being applied to the cigarette system and an updated value thereof.

The difference output of subtracter **123** is applied to potentiometer **124** having a slider **125** positioned to achieve stability, as discussed supra with regard to potentiometer **93** and slider **94** of FIG. **1**. The gain adjusted deviation signal at slider **125** is added, in addition network **126**, to a signal indicative of the averaged past target value, derived from an integrating or signal averaging network **127**. Network **127**, which may be of the RC low pass filter type, has a time constant on the order of 30 to 60 seconds to provide an effect similar to that attained by the sampling operation of FIG. **1**.

The output of signal averaging network **127** is fed back to the minuend input of subtracter **123** and to one input of adder **126**, to provide the signals indicative of the target offset presently being fed into the tobacco making apparatus. The output signal of adder **126** fed to multiplier **84** is converted to a true weight signal from the percentage signal which had been processed.

While the system of FIG. **5** has been described as a modification of the FIG. **1** embodiment, it is to be understood that the principles are equally applicable to the system of FIG. **4**. In particular, the percent reject output signal of converter **121** could be applied directly to subtracter **101** and each of the other elements connected therewith.

Reference is now made to FIG. **6** of the drawings wherein there is disclosed still another embodiment of the invention, wherein target offset is determined directly in response to standard deviation of the density variations within rod **19** as it passes the gauging station comprising source **22**. In the system according to FIG. **6**, elements **131**, **132** and **134–141** replace classifying network **28** and elements **71–79** and **81–83** of FIG. **1**. The gauge network **24** which provides the input, and the subtraction network **92** which provides the output signals, are the same elements shown in FIG. **1**. To determine maximum

profit in terms of target offset from a lower limit, standard deviation can be determined in accordance with well known techniques and algebraically combined with predetermined factors. In particular, the mathematical relationship between desired target relative to lower limit and standard deviation is:

$$(CT-LL)\%=1.2\sigma\%+1.8\% \quad (6)$$

Referring now more particularly to FIG. 6, the output signal of gauging network **24** is applied to variance computer **131**, which may be of the type disclosed in U.S. Pat. No. 2,965,300 to Radley et al. Computer **131** includes a clock source so that it periodically derives an output signal in accordance with variance, as dictated by Equation (1) supra. The variance output of computer **131** remains constant between the activation of the clock source, whereby the computer output is a series of constant amplitude voltages which have virtually step function transitions, similar to the output of digital-to-analog converter **74**.

The output of variance computer **131** is applied to conventional analog computer type square root network **132**. The output of square root circuit **132**, a DC voltage directly proportional to the standard deviation of the output of gauge **24** over a predetermined time interval, is converted to a percentage of standard weight in division circuit **134**, having a divisor input source **135** that is a constant voltage set in accordance with the standard weight setting **26** of gauge network **24**. The standard deviation percentage output of division network **134** is applied to an analog computing network which solves Equation (6).

The analog computer circuit for solving Equation (6) includes potentiometer **136**, having input terminals responsive to the output voltage of division circuit **134**. Tap **137** of potentiometer **136** is set in accordance with the 1.2 proportionality factor of Equation (6) and supplies a voltage commensurate with 1.2σ in terms of standard weight percentage to one of the inputs of summing network **138**. The other input to summing network **138** is a DC analog voltage commensurate with the 1.8 percentage factor of Equation (6), as derived from slider **139** of potentiometer **140** that is driven with a constant DC voltage at terminal **141**.

The resultant output of summing network **138** is a DC analog voltage commensurate with the deviation from the lower limit for the desired target to achieve maximum profit. The output voltage of summing network **138** is processed identically to the output voltage of summing network **83**, FIG. **1**, or in target resetting network **86**.

The concept of computing the deviation from a present standard deviation and an updated standard deviation, as set forth in the embodiment of FIG. **4**, is equally applicable to the embodiment of FIG. **6**. In particular, the output of division circuit **134** can be compared directly with a signal proportional to present standard deviation as computed by an analog computer network responsive to the output of subtraction network **91**, FIG. **4**, in accordance with:

$$\sigma\%=0.833(CT-LL)\%-1.5 \quad (7)$$

According to another aspect of the invention, the profit of a process controller can be optimized by fabricating a quantity of defective product that is put into the stream of commerce and determining what adverse effects the defective produce has on sales of the product. A penalty factor is provided for each defective product put into the stream of commerce and utilized in determining the control target or average value to enable achievement of optimum results equated to maximize profit.

In the specific alternate embodiment about to be described, cigarettes having a weight less than a lower limit are not rejected but are allowed to pass into the stream of commerce with the understanding that such cigarettes are likely to result in a dissatisfied customer and adversely affect future sales of the cigarettes by a predetermined factor, referred to as a penalty factor. In the present instance, a 2:1 penalty factor is provided for each defective cigarette passed into the stream of commerce. The standard deviation, σ, of the cigarettes produced is correlated into dissatisfied customers, to control the cigarette average weight (CT). As the average weight of each cigarette produced decreases, for a given value of σ, the number of dissatisfied customers is expected to increase.

As the value of σ increases, for a given value of average cigarette weight, the number of dissatisfied customers increases. The number of dissatisfied customers as a function of standard deviation and average value is cumulative in that a relatively small number of customers is dissatisfied with a cigarette having a weight of 1,000 milligrams but a considerably larger number is dissatisfied with cigarettes having an average weight of 950 milligrams. To determine the total customer dissatisfaction, therefore, it is necessary to accumulate or integrate the number of dissatisfied customers for each cigarette average weight from the lowest standard deviation to the actual highest standard deviation. This cumulative total of customer dissatisfaction is multiplied by a penalty factor relating to the likelihood of reduced future sales as a result of customer dissatisfaction.

A set of curve illustrating production costs, customer dissatisfaction costs and optimum control target as a function of control target and standard deviation is illustrated in FIG. **7**. In the curve of FIG. **7**, it is assumed that a 2:1 customer dissatisfaction penalty is provided, i.e., for each defective cigarette put into the stream of commerce, the manufacturer suffers a penalty equal to twice the profit he would normally make from that cigarette. For example, if the profit per cigarette were normally 0.05 cents, the penalty would be 0.1 cents and the manufacturer would lose 0.05 cents for each dissatisfied customer.

Referring now more specifically to FIG. **7**, cost is plotted as a function of average cigarette weight as a percentage of standard weight, CT percent. A pair of exemplary values of CT percent are illustrated by dashed straight lines **201** and **202**, indicating cigarette average weights of 85 percent and 100 percent of standard weight, respectively. Dashed curves **203–208** indicate the cost to the manufacturer in customer dissatisfaction for these different standard deviations, based upon the 2:1 penalty ratio for standard deviations of **1** percent through **6** percent, respectively. It is seen from curves **203–208** that with a very small standard deviation of 1 percent the cost to the cigarette manufacturer due to defective products getting into the stream of commerce is very small if the average weight of the cigarette is maintained greater than 85 percent of standard weight. As the standard deviation increases, whereby a greater percentage of defective cigarettes is likely to be produced, the cost to the cigarette manufacturer increases as a result of customer dissatisfaction, as shown by curves **203–208**. Each of curves **203–208** is asymptotic to a 0 cost line for average cigarette weight approaching infinity and increases in value for decreasing values of CT percent. At any particular value of CT percent the value of each of curves **203–208** is directly related to the value of σ with which it is associated.

Also plotted on FIG. **7** is straight line **209** which shows the cost of producing cigarettes, in terms of tobacco, as a function of CT percent. Curve **209** is a straight line because the cost of producing the cigarettes increases directly as the average weight of the cigarettes increases. Costs relating to factors such as paper, machinery and power, are so minimal as to have virtually no effect on production cost curve **209**.

To determine the cost of producing cigarettes with optimum profit, taking into account the customer dissatisfaction cost curves **203–208** and the tobacco cost curve **209**, cost values at corresponding average cigarette weights along the two curves are added together to produce total cost curves **211–216** for the six values of σ. The minimum value of each of curves **211–216** gives the value of CT for maximum profit for each σ to enable optimum target curve **217** to be produced. Hence, to derive the point P_{11} on curve **217**, which gives the value of CT percent that produces the most profit for a σ=1 percent, curve **203** is added to line **209** to derive curve **211**, the minimum value on curve **211** is found and correlated with a value of CT percent. Similarly, the values of P_{12}–P_{16} are successively

derived by combining the different values of curves **204–208** with the values of curve **209** at common values of CT to produce curves **212–216** and the minimum of each of curves **212–216** is correlated with a different CT percent. Curve **217**, in actuality, is slightly nonlinear but can be approximated closely as a straight line function, similarly to the manner by which the straight line function of FIG. **3** was approximated.

To control a process, such as the process illustrated in FIG. **1**, with a curve based on FIG. **7**, the value of σ for the process is computed. From the computed value of σ, a value of CT is calculated which will give optimum profit. The value of CT which will give optimum profit is compared with a value of CT previously utilized to control the average cigarette weight and the deviation between the two values enables a new value for CT to be derived. As in the previously described embodiments, a weighting factor is included for the deviation between the desired and previous values of CT to prevent overshoot. Of course, any embodiment utilizing the principles of FIG. **7** does not include the reject and reclamation apparatus of FIG. **1**, indicated as including synchronous delay **44**, reject kicker **45**, solenoid **46** and reclamation processor **47**. Further, the fraction defective computing apparatus of FIG. **1** would be replaced with a standard deviation type computer, of the type described in conjunction with FIG. **6**.

Reference is now made specifically to FIG. **8** of the drawings wherein there is illustrated an embodiment of the invention relaying upon the optimum target curve **217** of FIG. **7**. In the system according to FIG. **8**, elements **131**, **132**, **134**, **135** and **221–226** replace classifying network **28** and elements **81–83** of FIG. **1**, and network **86** is modified as described hereinafter. In the system of FIG. **8**, the process standard deviation (σ) as a percentage of standard weight is computed by circuit elements comprising variance computer **131**, square root network **132** and division network **134**, driven in response to the output of gauge network **24** and standard weight circuit **135** in the manner indicated supra with regard to FIG. **6**. The output of division network **134**, a DC voltage indicative of standard deviation as a percentage of standard weight, is applied across the terminals of potentiometer **221**, having a tap **222** set in accordance with the slope of curve **217**, FIG. **7**. The DC voltage at tap **222** is added in analog computer addition network **226** to a constant DC voltage derived from slider **223** of potentiometer **224**, energized by a constant positive DC voltage at terminal **225**. The voltage derived from tap **223** is commensurate with an offset cost value of curve **217**, whereby the output voltage of adding network **226** is indicative of the value of CT on curve **217** corresponding with the value of σ derived by division network **134**. Thereby, the output signal of addition network **226** is a DC voltage indicative of the average weight of cigarettes produced during a just completed time interval which will result in optimum operation of the cigarette processor of FIG. **1**, if no cigarettes are rejected and a 2:1 penalty factor is assigned for all cigarettes which result in customer dissatisfaction.

The desired value of cigarette average weight for the just completed segment of the process operation is compared with the previous value of desired average weight in network **86**, which functions in a manner similar to network **86** described supra in conjunction with FIG. **1**. In the network **86** of FIG. **8**, however, the desired average weight is compared with the previous desired average weight directly and no subtraction of lower limit values is included. Thereby, network **86** of FIG. **8** differs from that of FIG. **1** by being responsive directly to the value of CT, as derived from adder **226**, and does not include a subtracter **91**. Instead, the subtracter **92** in the network of FIG. **8** is driven directly by the output of analog delay network **88**, as is adding network **89**. As in the system of FIG. **1**, the system of FIG. **8** includes potentiometer **93**, having slider **94**, whereby a damping factor is provided for calculated deviations between previous desired values, as derived from analog delay network **88**, and the most recently computed cigarette average weight value.

To consider the operation of the system of FIG. **8**, initially assume that stable operation at σ=2% and CT=87.5% has been achieved with a total cost indicated by point P_{12}, FIG. **7**. Next assume that the tobacco input density spread suddenly changes so that σ jumps from 2 percent to 3 percent and cost jumps to the point indicated by P_{22}, FIG. **7**. At point P_{22} profit is no longer optimized because the customer dissatisfaction cost has increased due to the larger number of low weight, undesirable cigarettes being sold. To decrease customer dissatisfaction and again maximize profit, the average cigarette weight must be increased so that a lower number of undesirable, low weight cigarettes will be sold. The cost of the low weight undesirable cigarettes will, however, be greater for σ=3% than for σ=2% because of the added tobacco in each cigarette and the larger quantity of undesirable cigarettes that will reach the market. Maximum profit for σ=3% is achieved by operating knife **16** of the FIG. **1** system so that the average cigarette weight is gradually changed from point P_{22} to point P_{13}.

In the FIG. **7** system, under the initial stabilized condition, the σ=2% output of divider **134** is translated into a value of CT of 87.5 percent by the network including adder **226**, whereby cigarettes costing 0.05 cents are produced. In response to the change of σ from 2 percent to 3 percent, the desired target value signal derived from adder **226** jumps to approximately 90 percent. The 90 percent signal derived from adder **226** is compared with the previous desired average weight value signal of 87.5 percent in network **86**. Network **86** responds to the difference between the two desired weight signals to translate gradually the average weight of each unit length of cigarette rod from 87.5 percent to 90 percent of standard weight to maximize profit and produce cigarettes costing 0.052 cents.

While there have been described and illustrated several specific embodiments of the invention, it will be clear that variations in the details of the embodiments specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims. For example, the concepts of the present invention can be utilized to control the standard weight deviation input to summing circuit **29** on a manual basis in response to observations of meter **95**.

The analog computer arrangements above described are particularly adapted for profit maximizing control of a single processing machine, whereas in many plants, such as some cigarette manufacturing plants, a number of similar machines are operating simultaneously. In this case the practice of the invention is preferably implemented by using a digital computer which is operated on a time sharing basis to serve a number of machines in a manner similar to that described in U.S. Pat. No. 3,147,370, issued Sept. 1, 1964, to W. B. Lowman. The data for the profit maximizing functions, such as those shown graphically in FIGS. **3** and **7**, are stored in the computer memory, the control targets for the various machines are computed sequentially in response to the input data, and the updated target setting signals are routed to the several machine controllers on a periodic basis. Since the digital computer preferably uses the conventional table look-up system, the actual points on the profit maximizing curves, as at **61** and **217**, are used instead of the linear approximations thereto, so that the small errors due to nonlinearity are avoided.

We claim:

1. A system for controlling the average value of a processor or equipment output to achieve maximum economic profit, said output having a variable spread of values, comprising gauge means for deriving a response indicative of the value of a property of the processor or equipment output, means responsive to the gauge means response for deriving a first signal indicative of the spread of values of the property, means responsive to the first signal for deriving a second signal indicative of the average value of the property which maximizes profit of the processor or equipment for the particular spread

of values determined by said first signal deriving means, said second signal deriving means selecting said average value represented by said second signal in accordance with said spread so that a significant percentage of the processor or equipment output will have a value which renders said percentage undesirable for its intended use, said percentage increasing for larger spreads, said second signal deriving means continuing to increase said percentage so long as the economic profit is thereby increased, and decreasing said percentage when the economic profit decreases due to the increasing counteracting economic loss caused by the increase in said undesirable percentage, and means responsive to the second signal for activating the processor or equipment so that the average value of the property approaches the average value determined by said second signal deriving means.

2. The system of claim 1 wherein the first signal deriving means includes means for computing standard deviation as a measure of the spread of values.

3. The system of claim 1 wherein the first signal deriving means includes means for computing the spread of values as a ratio of the property values outside a limit value to the total property values for a fixed interval.

4. The system of claim 1 wherein the first signal deriving means includes means for computing the spread of values as a ratio of the property values outside a limit value to the total property values for a fixed interval which is a function of time.

5. The system of claim 1 wherein the first signal deriving means includes means for computing the spread of values as a ratio of the property values outside a limit value to the total property values for a fixed interval which is a function of output quantity.

6. The system of claim 3 wherein said computing means includes means for deriving a binary signal in response to the gauge means response having a value outside the limit value.

7. The system of claim 6 wherein said binary signal deriving means includes an integrator responsive to a constant voltage indicative of the limit value linearly combined with the gauge means response.

8. The system of claim 1 wherein the first signal deriving means includes means for computing the spread of values as a ratio of the property values outside a limit value to the total property values for a fixed interval which is a function of time, and wherein said computing means includes means responsive to the number of binary signals derived in a fixed time interval, said binary signals derived in response to the gauge means response having a value outside the limit value.

9. The system of claim 6 wherein the fixed interval is a function of the output quantity, and said means for deriving the second signal is responsive to the number of binary signals derived for a fixed output quantity.

10. The system of claim 1 wherein the second signal deriving means includes means for deriving said second signal as an output indicative of the deviation of said average value from a reference value for the property.

11. The system of claim 10 wherein the second signal deriving means further includes means for combining the first signal with a constant amplitude signal in accordance with:

$$K_1 \times S + K_2$$

where:

K_1 is constant proportionality factor determined by economic properties of the processor or equipment,

S is the amplitude of the first signal, and

K_2 is the amplitude of the constant amplitude signal, determined by economic properties of the processor or equipment,

to derive an indication of average value deviation from the limit value.

12. The system of claim 10 further including means responsive to the first signal and the output of the second signal deriving means for deriving another average value signal in response to a previously derived average value signal.

13. The system of claim 12 further including means responsive to the second signal for deriving another signal indicative of a previously derived spread indicating signal, and means for determining the deviation between the previously derived spread indicating signal and the spread indicated by the first signal.

14. The system of claim 1 wherein said activating means comprises means for activating said processor or equipment so that the average value of the property substantially equals the average value determined by said second signal deriving means.

15. A system for controlling the average weight of cigarettes during manufacture by a cigarette making equipment comprising gauge means for deriving a response indicative of the weight of a predetermined length of cigarette rod, means responsive to said gauge means for deriving a first signal indicative of the spread of weights in said lengths, means responsive to the first signal for deriving a second signal indicative of the average weight for said predetermined lengths which maximizes profit of the equipment for the particular spread of weights determined by said first signal deriving means, said second signal deriving means selecting said average weight represented by said second signal in accordance with said spread so that a significant percentage of the cigarette rod predetermined lengths has a weight less than a limit weight, said percentage increasing for larger spreads, said second signal deriving means continuing to increase said percentage so long as the economic profit is thereby increased, and decreasing said percentage when the economic profit decreases due to the increasing counteracting economic loss caused by the increase in said percentage having a weight less than said limit weight, and means responsive to the second signal for activating the equipment so that the average weight for the predetermined lengths approaches the average weight determined by said second signal deriving means.

16. The system of claim 15 including means for combining the spread indicating signal with a constant signal to derive a third signal indicative of deviation of said average weight from the lower limit, memory means responsive to said third signal, means responsive to said memory means for deriving a feedback signal indicative of a previously determined value of said third signal, and means for comparing the third signal derived by said combining means with the previously determined value of said third signal to modify the average value.

17. The system of claim 15 including memory means for deriving a third signal indicative of a previous value of the second signal, means responsive to said third signal for comparing the previous value of the second signal with the second signal derived by said second signal deriving means to modify the average value.

18. The system of claim 15 including memory means for deriving a third signal indicative of a previous value of the second signal, means responsive to said third signal for comparing the previous value of the second signal with the second signal derived by said second signal deriving means to modify the average value.

19. The system of claim 18 wherein the memory means derives the second signal that indicates average weight.

20. A system for controlling the average value of a property of discrete articles produced by a processor or equipment to achieve maximum profit, said property having an established limit value and an initial average value, comprising means responsive to said property of the articles for deriving a first signal indicative of the fraction thereof that is defective, means responsive to the first signal for deriving a second signal indicative of a new average value of the property which maximizes profit of the processor or equipment, said new average value being selected by said second signal deriving means so that a significant percentage of the processor or equipment output is defective, said percentage increasing for larger indications of fraction defective, said second signal deriving means continuing to increase said percentage so long as the economic profit is thereby increased, and decreasing said percentage when the economic profit decreases due to the increasing counteracting economic loss caused by the increase

in said fraction defective, and means responsive to the second signal for activating the processor or equipment so that the average value of the property substantially equals the new average value determined by said second signal deriving means.

21. A system for controlling the average weight of cigarettes during manufacture by cigarette-making equipment, said weight having a predetermined limit value and an initial average value, comprising means responsive to the cigarettes for deriving a first signal indicative of the percentage thereof that is defective, means responsive to the first signal for deriving a second signal indicate of a new average weight for the cigarettes which maximizes profit of the equipment, said new average weight being selected by said second signal deriving means so that a significant percentage of the cigarettes has a weight less than said limit value, said significant percentage increasing for larger defective percentages, said second signal deriving means continuing to increase said percentage so long as the economic profit is thereby increased, and decreasing said percentage when the economic profit decreases due to the increasing counteracting economic loss caused by the increase in said defective percentage, and means responsive to the second signal for activating the equipment so that the average weight of the cigarettes approaches the average weight determined by said second signal deriving means.

22. The system of claim 21 wherein said second signal deriving means includes means for adding a constant amplitude signal to another signal directly proportional to said first signal.

23. A system for controlling the average weight of cigarettes during manufacture by cigarette-making equipment, said weight having a predetermined limit value and an initial average value, said equipment including means for separating defective cigarettes from acceptable cigarettes, means for reclaiming the defective cigarettes and means for feeding the reclaimed cigarettes back to an input of the equipment, said system comprising means for detecting defective cigarettes being produced by said equipment, means responsive to said detecting means for activating said separating means in synchronism with the passage of defective cigarettes into a zone defining said separating means, means responsive to said detecting means for deriving a first signal indicative of the percentage of cigarettes that is defective, means responsive to the first signal for deriving a second signal indicative of a new average weight for the cigarettes which maximizes profit of the equipment, said new average weight being selected by said second signal deriving means so that a significant percentage of the cigarettes has a weight less than said limit value, said percentage increasing for larger defective percentages, said second signal deriving means continuing to increase said percentage so long as the economic profit is thereby increased, and decreasing said percentage when the economic profit decreases due to the increasing counteracting economic loss caused by the increase in said defective percentage, and means responsive to the second signal for activating the equipment so that the average weight of the cigarettes substantially equals the average weight determined by said second signal deriving means.

24. A system for controlling the average value of a processor output to achieve maximum economic profit, said output having a variable spread of values, said processor including means for separating defective output from an acceptable output and means for reclaiming the defective output for reuse comprising gauge means for deriving a response indicative of the value of a property of the processor or equipment, means responsive to the gauge means response for deriving a first signal indicative of the spread of the values of the property, means responsive to the first signal for deriving a second signal indicative of the average value of the property which maximizes profit of the processor or equipment for the particular spread of values determined by said first signal deriving means, said average value and spread being such that a significant percentage of the processor or equipment output has a value outside of a limit value, said percentage increasing for larger spreads, means responsive to the second signal for activating the processor or equipment so that the average value of the property substantially equals the average value determined by said second signal deriving means, means responsive to said gauge means for deriving an indication of which portion of the output is defective, and means responsive to said defective indication means for activating said separating means in synchronism with defective output being in a zone defined by said separating means.

25. A system for determining the amount by which a target value should be displaced from a reference target to achieve maximum profit for a processor deriving an output having a spread of values about an average value, said processor output being measured by gauge means deriving a response having a predetermined value in response to the output having a value equal to the reference target and deviating from the predetermined value as the output value deviates from the reference target, comprising means responsive to the gauge response for deriving a signal indicative of the spread of values, and means responsive to said signal for deriving an indication of the target deviation from the reference target that maximizes the economic profit of the processor, said target deviation being displaced by larger amounts from the reference target for small spreads relative to large spreads, said target deviation being less than a deviation between the reference target and a limit value beyond which the output is considered defective, the target deviation and spread of values being related such that for increasing spreads a greater percentage of the output has a value beyond the limit value, said indication deriving means including means for deriving said target indication as a percentage of said reference target.

26. The system of claim 25, wherein said indication deriving means includes means for deriving another signal indicative of the displacement between the lower limit and the target deviation from the reference target as a percentage of the reference target.

27. The system of claim 26 wherein said another deriving means includes means for combining the spread indicating signal with a second signal.

28. A control system for a processing apparatus using a costly input quantity for forming a product with a variable property dependent on said input quantity, said apparatus including means for adjusting the value of said variable property and producing concomitant changes in the amount of said input quantity used in forming said product, said control system comprising

gauging means for producing a succession of signals indicative of measured values of said property in successive portions of said product,

means for producing a signal indicative of a limiting value for said measured values, said limiting value being so selected that portions of said product having measured property values outside of the limiting value are deemed undesirable for their intended use, other portions of said product being deemed desirable for said use,

means providing a signal indicative of a temporary target value for said measured values,

means responsive to said measured value and said target value signals for controlling said adjusting means for said processing apparatus to regulate the average value of said measured values, said average value determining the cost of forming the product including both the desirable and undesirable portions thereof,

means responsive to said measured value signals for deriving a statistical quantity signal indicative of the spread of said measured values of said property,

means responsive to one of said target and statistical quantity signals for deriving a signal functionally related to an optimum value for the other of said target and statistical quantity signals in accordance with a statistically derived function dependent on said limiting value and relating the cost of using said input quantity as represented by said

target value to the cost of producing an amount of undesirable material which is functionally related to said statistical quantity signal so as to minimize the cost of producing the desirable portion of said product, and

means responsive to said optimum value related signal and the existing value of said other of said target and statistical quantity signals for producing a change in said temporary target value signal whereby said controlling means regulates said processing means to produce said product with a changed average value for said measured values, said change causing said other of said target and statistical quantity values to approach said optimum value whereby the cost of producing said acceptable portion of said product is minimized.

29. A control system as in claim 28 wherein said statistical quantity signal deriving means comprises means responsive to said measured value signals and said limiting value signal for deriving a reject portion signal, said reject portion signal being indicative of the spread of said measured values as a function of said limiting value and said target.

30. A control system as in claim 28 wherein said statistical quantity signal deriving means comprises means for computing the variance of said measured values, and

wherein said optimum value signal deriving means comprises means responsive to said variance for deriving an optimum value for said target value.

31. A control system for a processing apparatus using a costly input quantity for forming a product with a variable property dependent on said input quantity, said apparatus including means for adjusting the value of said variable property and producing concomitant changes in the amount of said input quantity used in forming said product, said control system comprising

gauging means for producing a succession of signals indicative of measured values of said property in successive portions of said product,

means for producing a signal indicative of a limiting value for said measured values, said limiting value being so selected that portions of said product having measured property values outside of the limiting value are deemed undesirable for their intended use, other portions of said product being deemed desirable for said use,

means responsive to said measured value signals and said limiting value signal for deriving a reject portion signal indicative of the portion of said product which is undesirable, said reject portion signal being further indicative of the cost of producing the undesirable portion of the product,

means providing a signal indicative of a temporary target value for said measured values,

means responsive to said measured value signals and said target value signal for controlling said adjusting means for said processing apparatus to regulate the average value of said measured values, said average value determining the cost of forming the product including both the desirable and undesirable portions thereof,

means responsive to one of said target value and reject portion signals for deriving a signal functionally related to an optimum value for the other of said target and reject portion values in accordance with a statistically function dependent on said limiting value and relating the cost of using said amount of said input quantity as represented by said target value to the cost of producing said undesirable portion of the product as represented by said reject portion signal so as to minimize the cost of producing the desirable portion of the product, and

means responsive to said optimum value related signal and the existing value of said other of said target and reject portion signals for producing a change in said temporary target value whereby said controlling means regulates said processing means to produce said product with a changed average value for said measured values, said change causing said other of said target and reject portion values to approach said optimum value whereby the cost of producing said desirable portion of said product is minimized.

32. A control system for a processing apparatus using a costly input quantity for forming a product with a variable property dependent on said input quantity, said apparatus including means for adjusting the value of said variable property and producing concomitant changes in the amount of said input quantity used in forming said product, said control system being adapted to regulate said processing apparatus so as to produce a major portion of said product deemed desirable for its intended use and a minor portion deemed undesirable for said use, said control system comprising

gauging means for producing a signal indicative of the measured value of said property,

means providing a signal indicative of a temporary target value for said measured value,

means responsive to said measured value and said target value signals for controlling said adjusting means for said processing apparatus to regulate the average value of said measured values, said average value determining the cost of forming the product including both the desirable and undesirable portions thereof,

means responsive to said measured value signal for deriving a statistical quantity signal indicative of the spread of said measured values of said property,

means responsive to one of said target and statistical quantity signals for deriving a signal functionally related to an optimum value for the other of said target and statistical quantity signals in accordance with a statistically derived function relating the cost of using said input quantity as represented by said target value to the cost of producing an amount of undesirable material which is functionally related to said statistical quantity signal so as to minimize the cost of producing said product,

means responsive to said optimum value related signal and the existing value of said other of said target and statistical quantity signals for producing a change in said temporary target value signal whereby said controlling means regulates said processing means to produce said product with a changed average value for said measured values, said change causing said other of said target and statistical quantity values to approach said optimum value whereby the cost of producing said product is minimized.

33. A control system as in claim 32 wherein said statistical quantity signal deriving means comprises means for computing the variance of said measured value signal, and

wherein said optimum value signal deriving means comprises means responsive to said variance for deriving an optimum value for said target value.

34. A system for controlling the average weight of cigarettes during manufacture by a cigarette making equipment comprising gauge means for deriving a response indicative of the weight of a predetermined length of cigarette rod, means responsive to said gauge means for deriving a first signal indicative of the spread of weights of said lengths, means responsive to the first signal for deriving a second signal indicative of the average weight for said predetermined lengths which maximizes profit of the equipment for the particular spread of weights determined by said first signal deriving means, said second signal deriving means selecting said average weight represented by said second signal in accordance with said spread so that some of the cigarette rod predetermined lengths have a weight to cause customer dissatisfaction, the amount of rod predetermined lengths causing dissatisfaction increasing for larger spreads, and means responsive to the second signal for activating the equipment so that the average weight of the predetermined lengths substantially equals the average weight determined by said second signal deriving means.

35. The system of claim 34 further including means responsive to said gauge means for rejecting those portions of the rod lengths having weights to cause customer dissatisfaction.

36. The system of claim 34 wherein the second signal deriving means includes a function generator for determining the effect on profit of the rod lengths causing customer dissatisfaction reaching the customer as a function of the spread of cigarette weight.

37. A method of controlling the average value of a processor or equipment output parameter to achieve maximum economic profit comprising producing a signal indicative of the spread values of the output parameter, and controlling the average value of the parameter in response to said signal so that for large spreads the percentage of output parameter having a value outside a limit for desirable values is greater than for small spreads, said controlling operation including adjusting the average value toward said limit to produce a larger percentage of output parameter having a value outside said limit so long as the economic profit is thereby increased, but adjusting the average value away from the limit when the economic profit decreases due to the increasing counteracting economic loss caused by the magnitude of said percentage.

38. The method of claim 37 further including the step of reclaiming that portion of the output having a value outside of the limit for desired values.

39. A method for controlling the average value of a processor or equipment output parameter having a predetermined limit for desirable values and an initial average value to achieve maximum economic profit comprising producing signals indicative of said limit value, said initial average value and the defective percentage of the output which is outside said desirable limit value, and controlling the average value of the parameter in response to said signals so that for large defective percentages the percentage of output parameter having a value outside a limit for desirable values is greater than for small defective percentages, said controlling operation including adjusting the average value toward said limit to produce a larger percentage of output parameter having a value outside said limit so long as the economic profit is thereby increased, but adjusting the average value away from the limit when the economic profit decreases due to the increasing counteracting economic loss caused by the magnitude of said percentage outside said limit.

40. A method of controlling the average value of a property of a processor or equipment output to achieve maximum economic profit, said output property having a variable spread of values, comprising the steps of producing a first signal indicative of the spread of values of said property, in response to said signal producing another signal indicative of the average value of the output property which maximizes profit of the processor or equipment for the particular spread of values indicated by said first signal, said average value being determined in accordance with said first signal so that a significant percentage of the processor or equipment output has a value outside of a limit value, said percentage increasing for larger spreads so long as the economic profit is thereby increased but so that said percentage is decreased when the economic profit decreases due to the economic loss due to the increasing percentage of the output having a property value outside the limit value, and activating the processor or equipment in response to said another signal so that the average value of the output approaches the average value indicated by said another signal for maximizing profit.

41. A method of controlling the average value of a property of articles produced by a processor or equipment to achieve maximum profit comprising the steps of deriving a signal indicative of the spread of values of the property of the articles produced, from said spread indicative signal producing a computed signal indicative of an optimum average value for the property based on the cost of materials utilized in the article manufactured and affecting said property as well as on the adverse effects of customer dissatisfaction due to some of the articles having property values less than a desirable value, said optimum average indicated by said computed signal minimizing the amount of material utilized to maximize profit taking into account the increasing cost of customer dissatisfaction as the number of articles having property values less than said desirable value is increased, and controlling the processor or equipment in response to said computed signal so that the average value of the articles is substantially the optimum average indicated thereby.

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