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[54] **NORMALIZED FUEL RATE COMPUTER**
5 Claims, 6 Drawing Figs.

[52] U.S. Cl. **235/184,**
235/150.21, 235/193

[51] Int. Cl. **G06g 7/70**

[50] Field of Search 235/184,
185, 193, 194, 197, 150.2, 150.21, 151.12,
151.34; 244/77

[56]

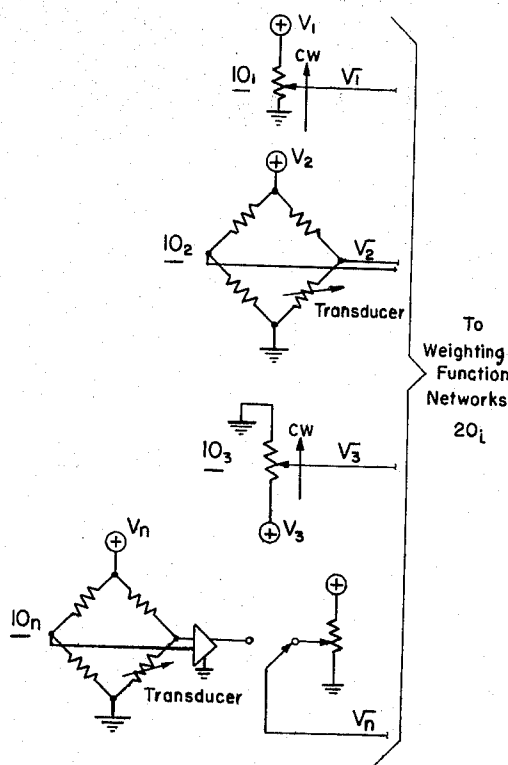
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Primary Examiner—Joseph F. Ruggiero

ABSTRACT: An analog computer simulates and/or determines on a real time basis the normalized fuel consumption of a ship's powerplant. A plurality of powerplant parameters are transformed into a form $(1 \pm \Delta p_i)$, and normalized fuel rate is computed by displaying a linearly combined sum of weighted replicas of signals embodying the several p_i 's.



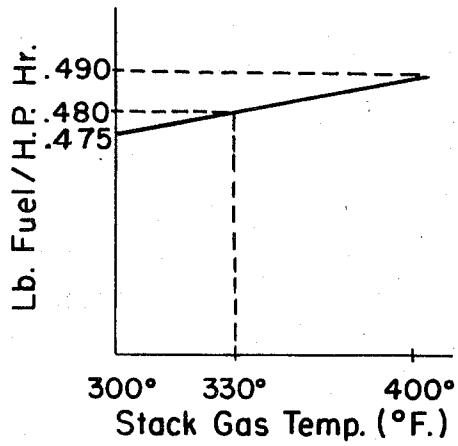


FIG. 1A

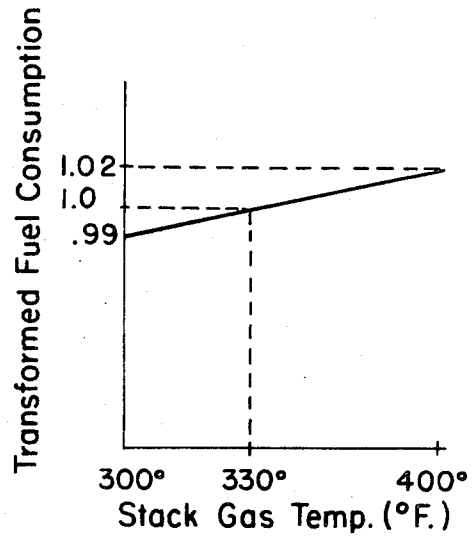


FIG. 1B

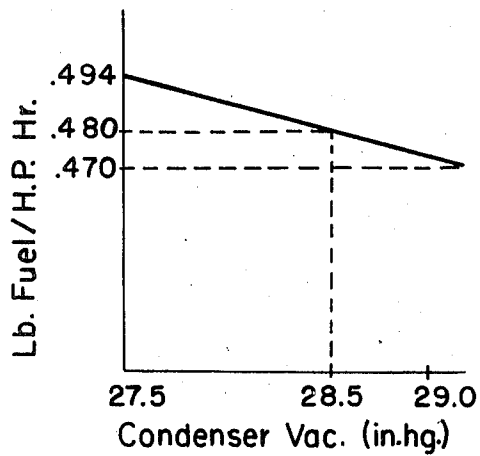


FIG. 2A

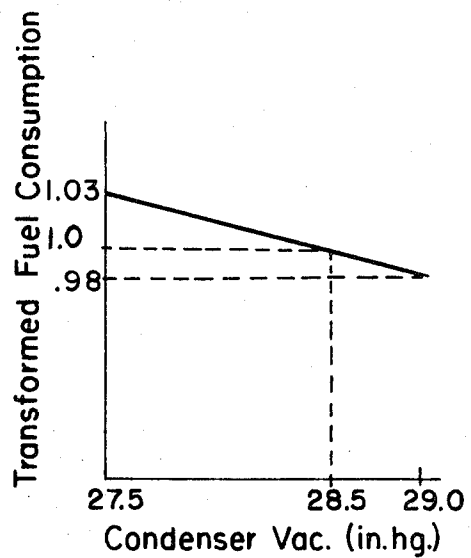
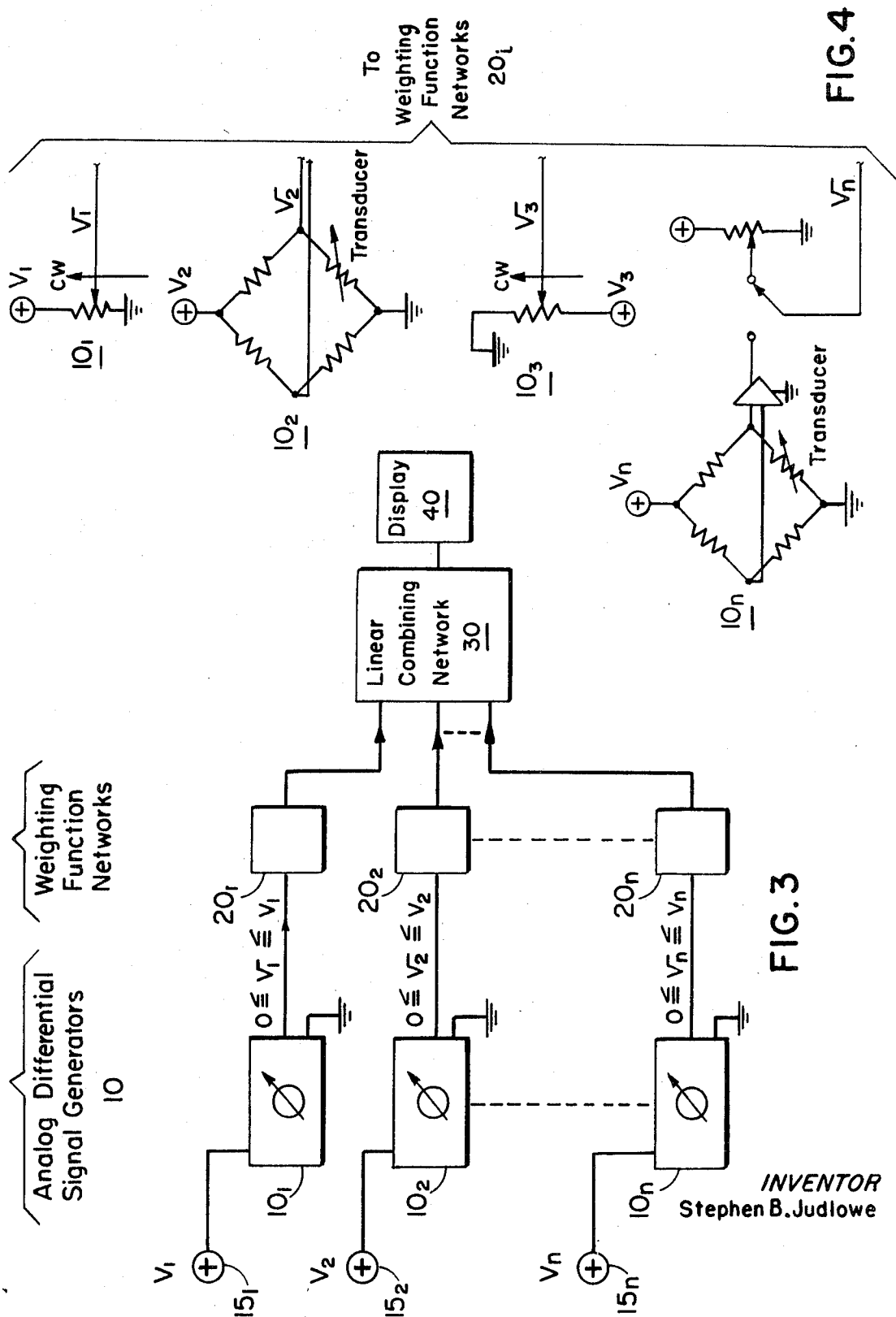


FIG. 2B

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NORMALIZED FUEL RATE COMPUTER

This invention relates to marine equipment and, more specifically, to a method and apparatus for computing and/or simulating a single figure of merit characterizing an entire ship's propulsion system, i.e., its normalized fuel rate.

Present day commercial shipping is evolving towards the use of relatively large vessels powered by propulsion systems of increasing capacity, complexity, and sophistication. To determine the status and operational efficiency of the propulsion apparatus, many powerplant parameters such as temperatures (e.g., boiler, feedwater, stack gas), pressured, external loads, and the like, as well as selected environmental conditions, are monitored. Continuous records of such data are typically made for the use of the ship's operating engineer and technicians, and for the organization owning or chartering the vessel.

However, this plethora of data is for the most part of little value to all but the most skilled personnel. These isolated data entries do not readily reveal the operational status of the composite power system, or the efficiency thereof. Further, even to one most skilled in these matters, it is difficult if not impossible to conveniently project the effect of varying combinations of the parameters on power plant efficiency.

It is therefore an object of the present invention to provide improved marine instrumentation and methodology.

More specifically, an object of the present invention is the provision of a single integrated computer which displays a single figure of merit characterizing a ship's composite propulsion system.

Still another object of the present invention is the provision of an instrument and method for simulating a ship's powerplant, and for providing variables which are readily adjustable to display the effect of differing values for various parameters on the fuel consumption efficiency of a vessel.

These and other objects of the present invention are realized in a specific, illustrative method and apparatus for characterizing the overall relative efficiency of a vessel's powerplant, i.e., by computing or simulating the rate of fuel consumption normalized by the useful horsepower output of the ship's powerplant. For an analog computing system, a plurality of transducers are employed to convert a corresponding plurality of sensed environmental conditions (temperatures, pressures, and the like) into signals of the form $k_i (1 \pm \Delta p_i)$ where the several positive or negative p_i quantities reflect a departure of the sensed signals from quiescent or "par 1" values. The transducer output signals are then supplied with weighted significance to a linear combining network.

The output from the combining network is displayed on a meter or other indicating device. As one or more conditions depart from their normal values, the display reading will increase or decrease, thereby respectively reflecting a corresponding decrease or increase in the normalized fuel rate, and thereby also in propulsion efficiency. For plant simulation applications, the condition-identifying signals may be directly generated and varied by an operator.

A complete understanding of the present invention, and of the above and other objects, features and advantages thereof are realized in illustrative embodiments thereof presented hereinbelow in conjunction with the accompanying drawing, in which:

FIGS. 1A and 2A indicate relationships between various ship's powerplant parameters and normalized fuel consumption;

FIGS. 1B and 2B respectively depict the relationships of FIGS. 1A and 2A transformed to the form $1 \pm \Delta p_i$;

FIG. 3 illustrates a block diagram of an analog fuel rate computer in accordance with the principles of the present invention; and

FIG. 4 depicts various input configurations for the computer of FIG. 3.

As is well known, the relationship between each parameter of a ship's propulsion system and the rate of fuel consumption may be determined from the powerplant heat (energy) balance. To determine the normalized fuel rate for any set of

operating conditions, one has heretofore inserted one set of operating values into the heat balance equations and, after many tedious manual computations, derived the normalized fuel consumption for that particular set of conditions. It has been difficult if not impossible to determine the effect of simultaneous changes in several operating parameters by reason of the many computations involved, these computations involving interrelations of the changing parameter(s).

In accordance with my invention, I first fix all but one of the operating parameters and let one condition vary, thereby determining the relationship between that parameter and normalized fuel rate (lbs. fuel/horsepower hr.). The relationship between normalized fuel consumption, and stack gas temperature and main condenser vacuum are shown in FIGS. 1A and 2A, and are illustrative of fuel dependencies for other relevant parameters. For concreteness, assume that 0.48 is the normal fuel consumption corresponding to a stack temperature of 333° F. and a normal vacuum of 28.5 inches Hg for a particular ship, and that temperature varies between 300° and 400° F. (corresponding to fuel consumptions of 0.475 and 0.49) while vacuum varies between 27.5 inches and 29.0 inches (fuel consumptions of 0.494 and 0.470). Assigning a relative weighting factor of 1.0 to the quiescent 0.480 fuel consumption, the ordinate relationship of FIGS. 1A and 2A may be transformed and normalized as shown in FIGS. 1B and 2B into the form $(1 \pm \Delta p_i)$, wherein fuel consumption varies -1 percent to +2 percent over the range of stack gas temperatures, and varies +3 percent to -2 percent with vacuum changes. Corresponding relationship may be established for all other ship's parameters, e.g., fuel specific gravity or heating value, main turbine steam inlet temperature and pressure, percent oxygen in stack gases, feedwater temperature, combustion air temperature, external electrical and steam load, and evaporator load.

The normalized fuel consumption N.F.C. of a ship may be expressed as a product of the individual factors, i.e.,

$$\text{N.F.C.} = K(1 \pm \Delta p_1)(1 \pm \Delta p_2) \cdots (1 \pm \Delta p_n) \quad (1)$$

where K is the "par" or normalized fuel consumption value (0.480 above), and the various Δp_i are the incremental fuel consumption variation factors caused by displacements of the various operational parameters from their normal values.

Expanding equation 1 and ignoring the constant K (which may be incorporated into an output display scale as discussed below), we have

$$\begin{aligned} \text{N.F.C.} = & 1 + \Delta p_1 + \Delta p_2 + \cdots + \Delta p_n + \Delta p_1 \Delta p_2 + \cdots \\ & \Delta p_1 \Delta p_n + \cdots + \Delta p_{n-1} \Delta p_n + \Delta p_1 \Delta p_2 \Delta p_3 + \cdots \\ & \Delta p_1 \Delta p_2 \cdots \Delta p_n \quad (2) \end{aligned}$$

The factors p_i are significantly less than 1 (see FIGS. 1B and 2B), and thus all differential cross products may be ignored to a high degree of approximation. Also the "1" factor conveys no intelligence and, when ignored greatly improves the accuracy and stability of the computing arrangements described below by obviating the need for any constant direct current subtraction (offset) signal to zero balance and adjust the computer.

An analog computer system for simulating a ship's propulsion system is shown in FIG. 3, and includes a plurality of analog signal generators 10, each of which is adapted to supply an output voltage V_i which is adapted to electrically represent a parameter differential Δp_i (but not the parameter par or normal value). A DC voltage V_i is supplied to each signal generator 10, and the output voltage V_i is continuously variable under operator adjustment from zero volts to V_i volts (the several " V_i "s may be the same or different). The signal generators may comprise tapped potentiometers with voltage and ground connected to the fixed terminals thereof, with the specific connection arrangement being opposite for parameters having positive and negative sloping incremental fuel consumptions.

The output voltages v_i from the several analog differential signal generators are each supplied to an associated weighting network 20, which supplies a weighted replica of the signal v_i to a linear combining arrangement 30. The combiner 30, in turn, supplies a signal to a display 40, e.g., a meter, which

signal represents the sum of the analog replicas developed by the weighting networks 40.

To illustrate, let the meter 40 have a full scale deflection of M units. Examining the relationship of FIG. 1B, the total change ΔP_1 in fuel rate attributable to stack gas temperature is 3 percent (1.02–0.99). Similarly, the change ΔP_2 caused by the main condenser vacuum is 5 percent (1.03–0.98).

The fuel meter deflection of M units is apportioned between all parameters under study. The total fuel rate change ΔP_i is given by

$$\Delta P = \Delta P_1 + \Delta P_2 + \dots + \Delta P_n.$$

Accordingly, the total meter 40 deflection M is apportioned such that

$$M \Delta P_i / \Delta P_i \quad (3)$$

scale units are assigned to the corresponding operating i th parameter. The assignment is effected by suitable selection of component values in the weighting function networks 20_i. For example, the meter 40 may be a voltmeter 40 having a full scale deflection of M volts, and the linear combining network 30 may comprise a summing resistive lattice and an operational amplifier to effect a gain A (e.g., unity) between any input of linear combiner 30 and the output thereof. Accordingly, each weighting network 20_i may advantageously comprise a voltage divider to divide the output V_i of the corresponding analog signal generator 10_i (a tapped potentiometer). The voltage division factor $V.D._i$ for each network 20_i comprises:

$$V.D._i M \times (\Delta P_i / \Delta P_i) \times 1 / V_i A \quad (4)$$

Alternatively, for an ammeter 40 of M full scale amperes, the combined network would be a current-summing node or network wherein the network 20_i comprises a voltage-to-current converting resistance of value R_i where

$$R_i = (V_i / M) \times (\Delta P_i / \Delta P_i) \quad (5)$$

Finally, in keeping with the elimination of zero balancing signal problems, the scale of the meter is calculated in terms of displacement signals only, i.e., the zero reading is 0.480 (0.99 (FIG. 1B) $\times$ 0.98 (FIG. 2B) $\times$...), i.e., par value multiplied by the product of the lower parameter displacement values, while the full scale reading is 0.480 (1.02 (FIG. 1B) $\times$ 1.03 (FIG. 2B) $\times$...), i.e., par multiplied by the product of the upper displacement limits.

To operate the FIG. 3 computer, the operator adjusts all variable differential signal generators 10_i to settings corresponding to normal operating values (if desired). This will automatically produce the par-normalized fuel consumption rate, e.g., a reading of 0.480 lbs. fuel/horsepower hr.—and this is effected without and DC offset signal whatever.

To determine normalized fuel consumption under any other set of operating conditions, an operator merely adjusts the signal generators 10_i to the corresponding settings (determined from calibration scales associated with the variable elements), and reads the fuel consumption on the display 40.

The above computational mode of operation simulates the entire ship's propulsion system, i.e., displays the normalized fuel consumption for any set of operating conditions programmed by the operator—adjustments of the analog generators 10_i. Alternatively, the generators 10_i may comprise the output of operating condition monitoring transducers, preferably balanced to read directly in terms of differentials (displacement from normal), such that the display 40 will indicate the actual instantaneous normalized fuel consumption of the ship. Moreover, any hybrid mixture of transducers and operator-controlled variable-voltage type potentiometers may be employed. Further, an alternatively selected switched couplet of a transducer and a variable voltage network may be employed, the meter 40 reading actual ship's fuel consumption when the transducer (all parameters) is connected into circuit; and calculated consumption (which may be varied to show the effect of changes in that parameter) when the variable network is connected into circuit. FIG. 4 depicts a hybrid input signal mixture comprising an operator controlled generator 10_i (positive slope for clockwise potentiometer tap

rotation); a transducer analog signal generator 10₂; an operator controlled generator 10₃ (negative slope for clockwise potentiometer tap rotation); and a switched combination 10_n.

It is to be understood that the above-described methodology and arrangements are only illustrative of the application of the principles of the present invention. Numerous other methods and arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention.

What is claimed is:

1. In combination in an analog arrangement for computing the normalized fuel consumption of a propulsion system, the relationship between normalized fuel consumption and each of a number n of operational parameters being expressible in the form $(1 \pm \Delta p_i)$, where n is any positive integer and Δp_i is any positive or negative number less than one which expresses the differential change in normalized fuel consumption as a function of the parameter value and wherein the range for each of the $n \Delta p_i$ is Δp_i , means for generating a continuous analog electrical signal representing each of the $n \Delta p_i$, plural weighting networks connected to said signal-generating means for providing a weighted replica of an associated Δp_i signal, means for linearly combining the n weighted signals, and display means for presenting the linearly combined signals, wherein said display means has a full scale presentation of M units, where M is any positive number, said weighting means including means for weighting each of said $n \Delta p_i$ signals for a full range display of

$$M \cdot \frac{\Delta P_i}{\sum_{k=1}^n \Delta P_k}$$

units.

2. A combination as in claim 1 further comprising a voltage source, and wherein said Δp_i signal-generating means includes a plurality of potentiometers each including fixed end terminals and a variable terminal, said potentiometers associated with positive and negative sloping functions $(1 + \Delta p_i)$ and $(1 - \Delta p_i)$ having their fixed terminals connected to said voltage source in an opposite polarity relationship.

3. A combination as in claim 2 wherein said Δp_i signal generating means includes a balanced parameter-monitoring transducer.

4. A combination as in claim 2 wherein said Δp_i signal-generating means includes a least one balanced parameter-monitoring transducer, and further includes switching means for connecting a selected one of said potentiometer variable terminals or said transducer to an associated one of said weighting networks.

5. The method for computing normalized fuel consumption of a propulsion system, the relationship between normalized fuel consumption and each of a number n of operational parameters being expressible in the form $(1 \pm \Delta p_i)$, where n is any positive integer and Δp_i is any positive or negative number less than one which expresses the differential change in normalized fuel consumption as a function of the parameter value, and wherein the range for each of the $n \Delta p_i$ is Δp_i , comprising developing an electrical signal proportional to each of the $n \Delta p_i$ displacement values, weighting the significance of the n signals, linearly combining the n weighted signals, and displaying a replica of the combined signals, wherein the display has a full scale presentation of M units where M is any positive number, wherein the signal weighting step weights each signal for a total display presentation of

$$M \cdot \frac{\Delta P_i}{\sum_{k=1}^n \Delta P_k}$$

units.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,634,670

Dated January 11, 1972

Inventor(s) Stephen B. Judlowe

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 1, column 4, line 20, before "means", " Δp_i " should
be -- ΔP_i --;

Claim 5, column 4, line 61, " Δp_i " should be -- ΔP_i --.

Signed and sealed this 8th day of August 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents