US006971982B1

(12) **United States Patent**
Kirsch

(10) **Patent No.: US 6,971,982 B1**
(45) **Date of Patent: Dec. 6, 2005**

(54) **APPARATUS FOR CENTRIFUGING A SLURRY**

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(73) Assignee: **Derrick Manufacturing Corporation**, Buffalo, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 239 days.

(21) Appl. No.: **10/138,202**

(22) Filed: **May 3, 2002**

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/133,889, filed on Apr. 26, 2002.

(51) **Int. Cl.**[7] **B04B 13/00**; B04B 1/20
(52) **U.S. Cl.** **494/8**; 494/53; 700/273
(58) **Field of Search** 494/1, 5, 7–10, 494/12, 27, 30, 42, 52–54, 84; 210/97, 103, 210/134, 143, 380.3; 700/273

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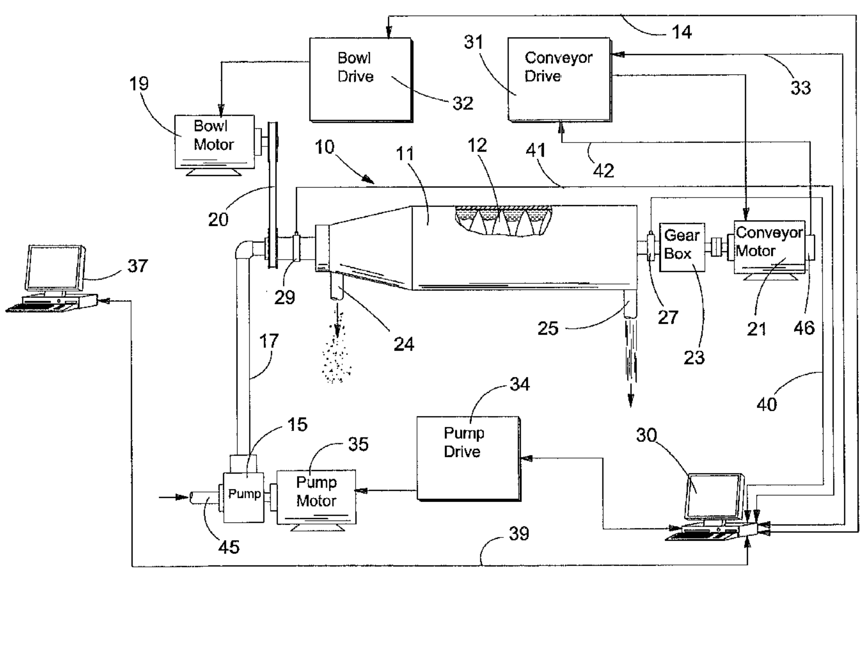
(57) **ABSTRACT**

A method and apparatus for centrifuging. The apparatus comprises a centrifuge for centrifuging a slurry, comprising a bowl driven by a bowl drive motor, a screw conveyor driven by a screw conveyor drive motor, a pump driven by a pump motor, a bowl drive unit operatively arranged to drive the bowl drive motor, a conveyor drive unit operatively arranged to drive the screw conveyor drive motor, a pump drive unit operatively arranged to drive the pump drive motor, and, a general purpose first computer specially programmed to control the bowl drive unit to drive the bowl drive motor at a first constant speed and to control the screw conveyor drive unit to drive the screw conveyor drive motor at a second constant speed and to monitor the torques of the bowl drive motor and the screw conveyor drive motor, while simultaneously controlling the pump drive unit to variably control flow of the slurry through the centrifuge so as to drive one of the bowl drive motor or the screw conveyor motor at a pre-set operating torque.

4 Claims, 37 Drawing Sheets



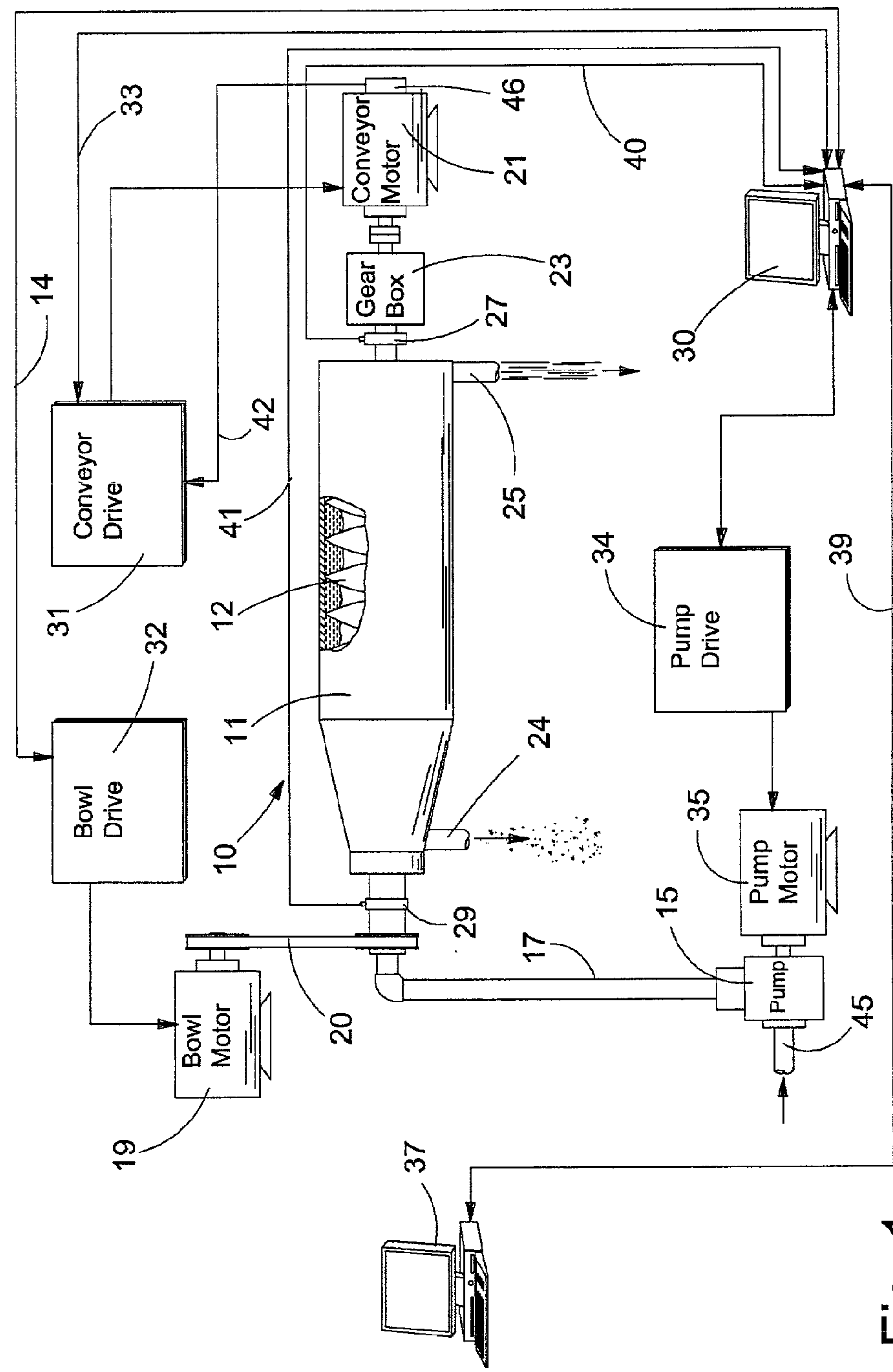

Conveyor Motor
Gear Box
Conveyor Drive
Bowl Drive
Bowl Motor
Pump Drive
Pump Motor
Pump
10
11
12
14
15
17
19
20
21
23
24
25
27
29
30
31
32
33
34
35
37
39
40
41
42
45
46

Fig. 1

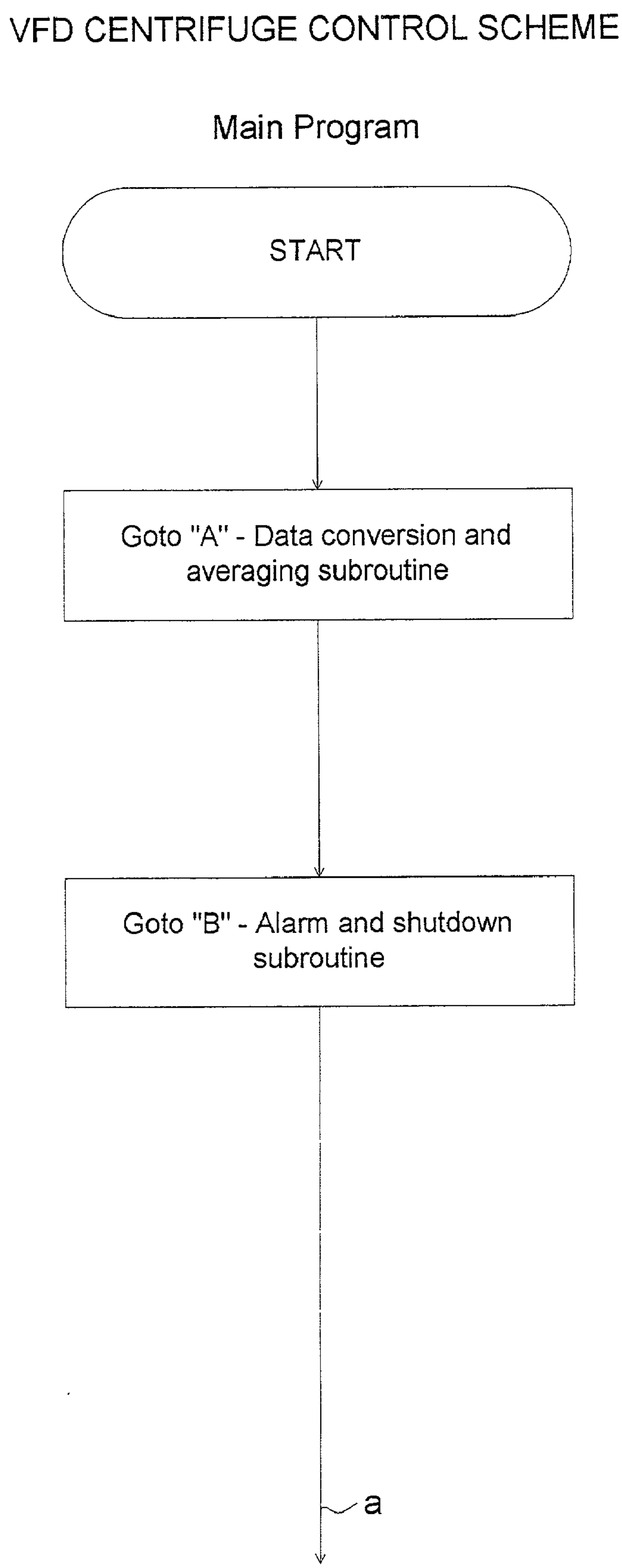

VFD CENTRIFUGE CONTROL SCHEME
Main Program
START
Goto "A" - Data conversion and averaging subroutine
Goto "B" - Alarm and shutdown subroutine
a

FIG 2

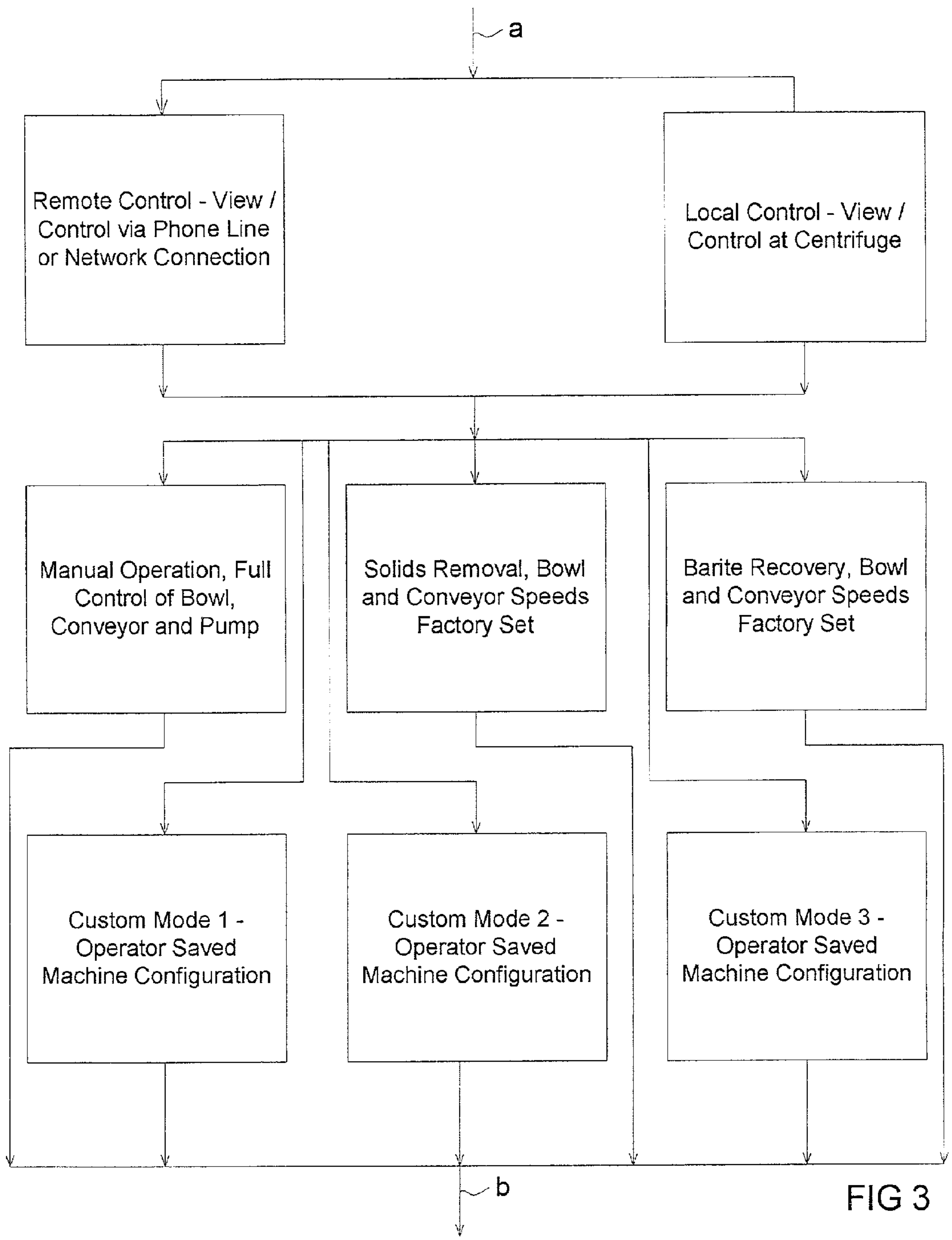

a
Remote Control - View / Control via Phone Line or Network Connection
Local Control - View / Control at Centrifuge
Manual Operation, Full Control of Bowl, Conveyor and Pump
Solids Removal, Bowl and Conveyor Speeds Factory Set
Barite Recovery, Bowl and Conveyor Speeds Factory Set
Custom Mode 1 - Operator Saved Machine Configuration
Custom Mode 2 - Operator Saved Machine Configuration
Custom Mode 3 - Operator Saved Machine Configuration
b

FIG 3

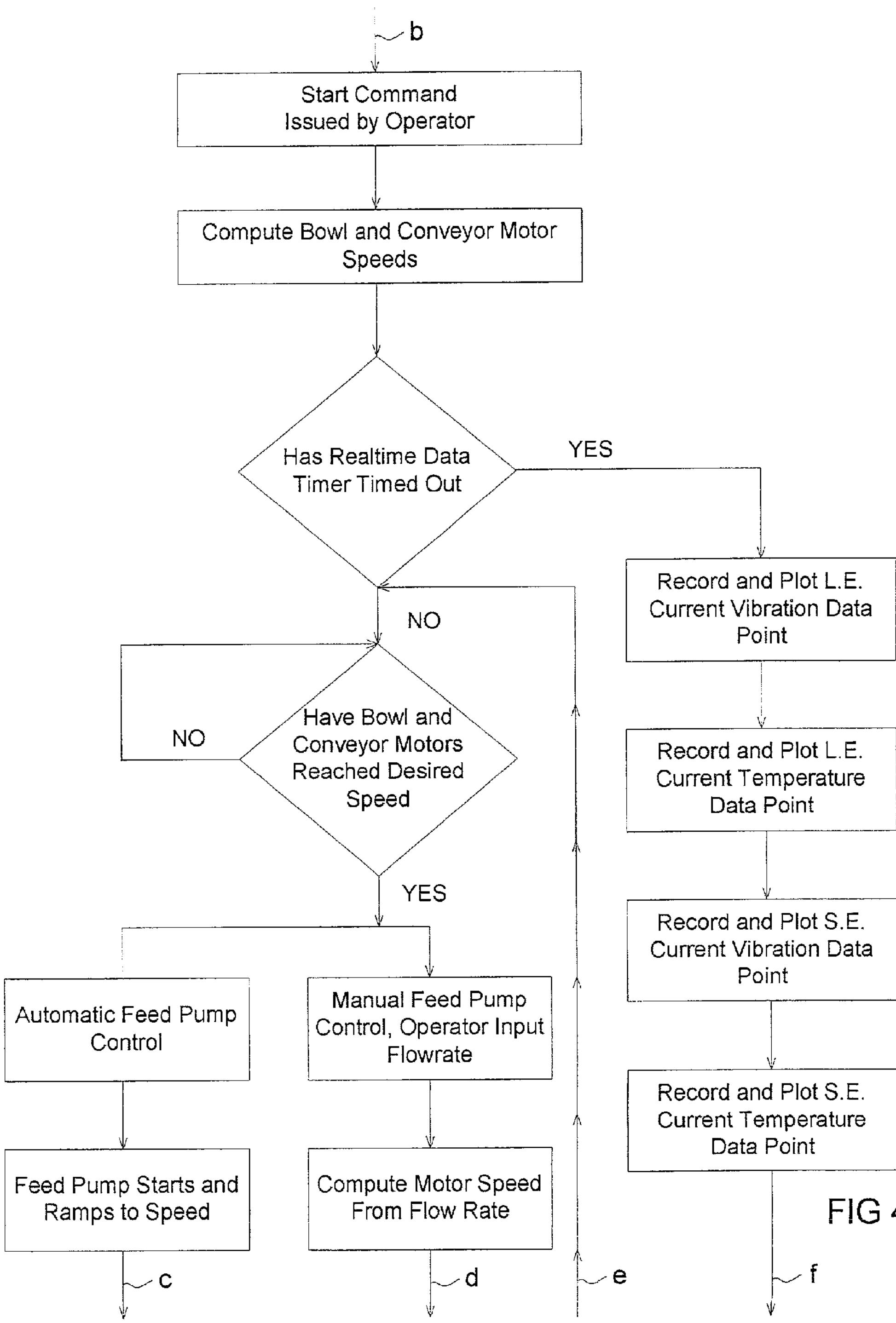

b
Start Command
Issued by Operator
Compute Bowl and Conveyor Motor
Speeds
Has Realtime Data
Timer Timed Out
YES
NO
Record and Plot L.E.
Current Vibration Data
Point
NO
Have Bowl and
Conveyor Motors
Reached Desired
Speed
Record and Plot L.E.
Current Temperature
Data Point
YES
Record and Plot S.E.
Current Vibration Data
Point
Automatic Feed Pump
Control
Manual Feed Pump
Control, Operator Input
Flowrate
Record and Plot S.E.
Current Temperature
Data Point
Feed Pump Starts and
Ramps to Speed
Compute Motor Speed
From Flow Rate
c
d
e
f

FIG 4

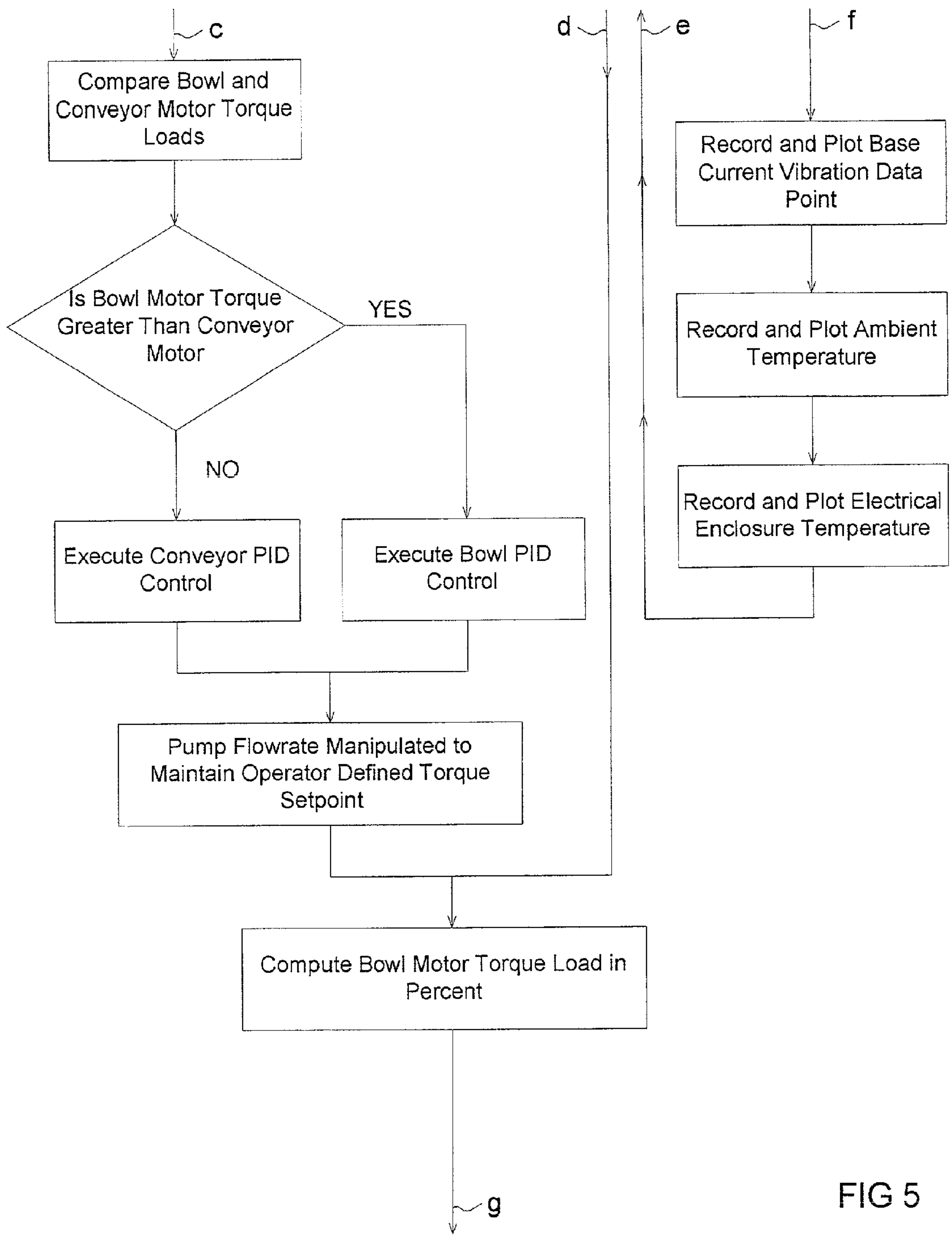

c
d
e
f
Compare Bowl and Conveyor Motor Torque Loads
Is Bowl Motor Torque Greater Than Conveyor Motor
YES
NO
Execute Conveyor PID Control
Execute Bowl PID Control
Pump Flowrate Manipulated to Maintain Operator Defined Torque Setpoint
Compute Bowl Motor Torque Load in Percent
g
Record and Plot Base Current Vibration Data Point
Record and Plot Ambient Temperature
Record and Plot Electrical Enclosure Temperature

FIG 5

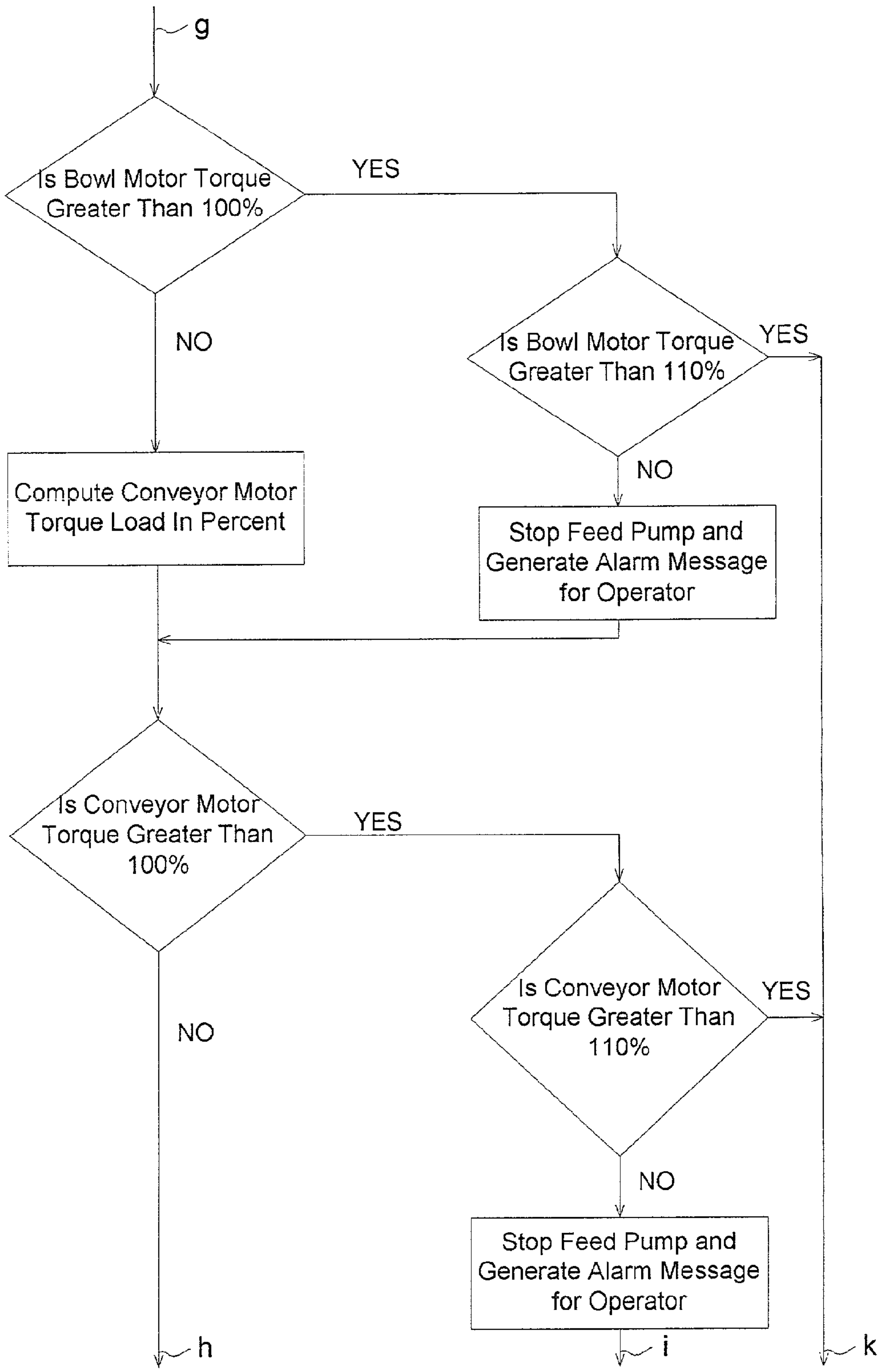

g
Is Bowl Motor Torque Greater Than 100%
YES
NO
Is Bowl Motor Torque Greater Than 110%
YES
NO
Compute Conveyor Motor Torque Load In Percent
Stop Feed Pump and Generate Alarm Message for Operator
Is Conveyor Motor Torque Greater Than 100%
YES
NO
Is Conveyor Motor Torque Greater Than 110%
YES
NO
Stop Feed Pump and Generate Alarm Message for Operator
h
i
k

FIG 6

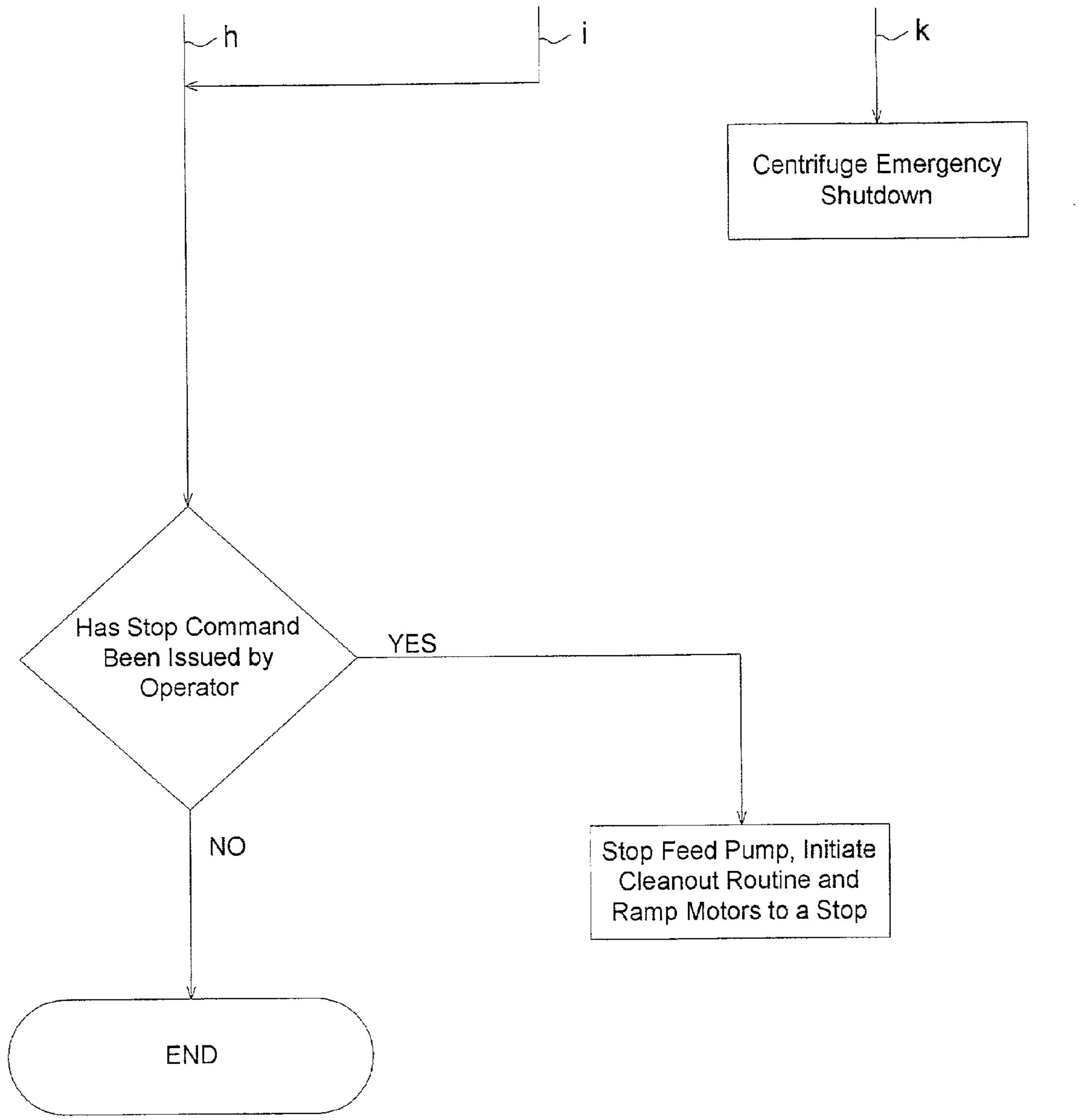

h
i
k
Centrifuge Emergency Shutdown
Has Stop Command Been Issued by Operator
YES
NO
Stop Feed Pump, Initiate Cleanout Routine and Ramp Motors to a Stop
END

FIG 7

Data Conversion and Averaging Subroutine

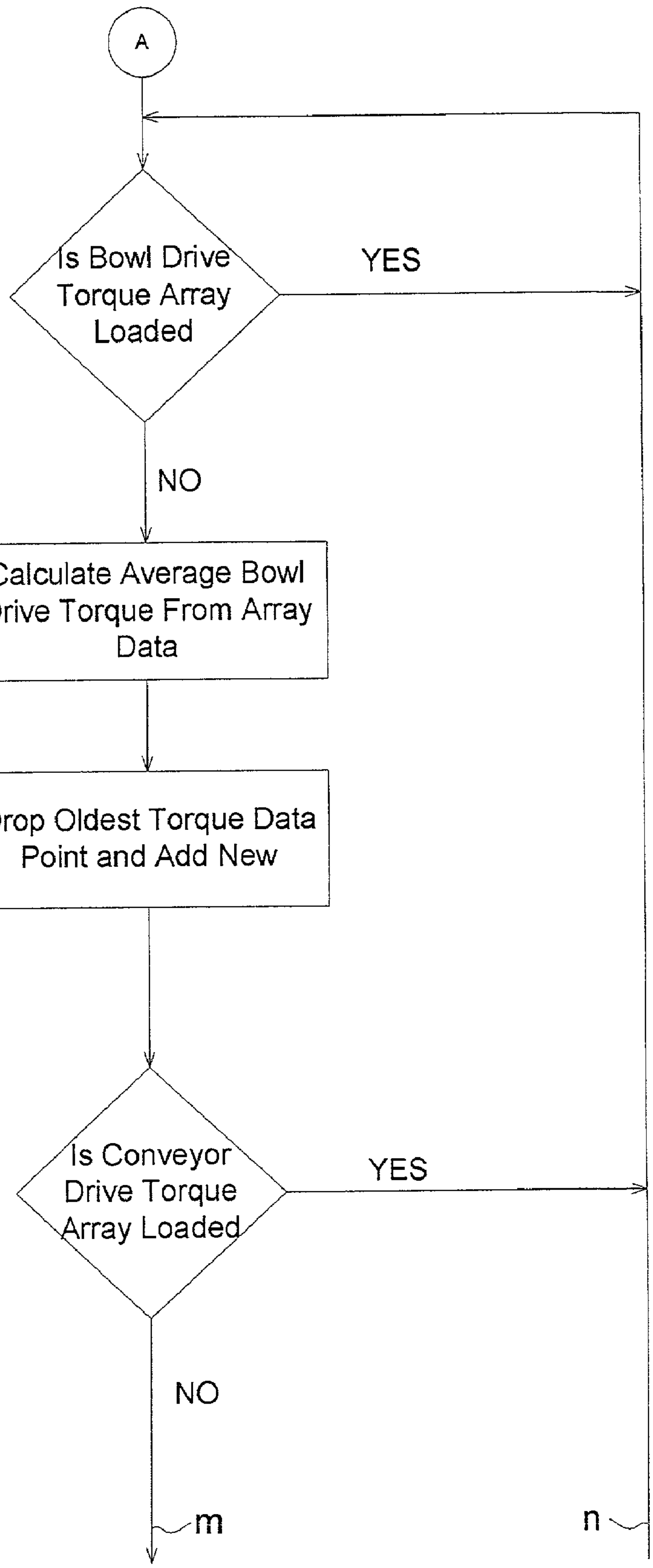


FIG 8

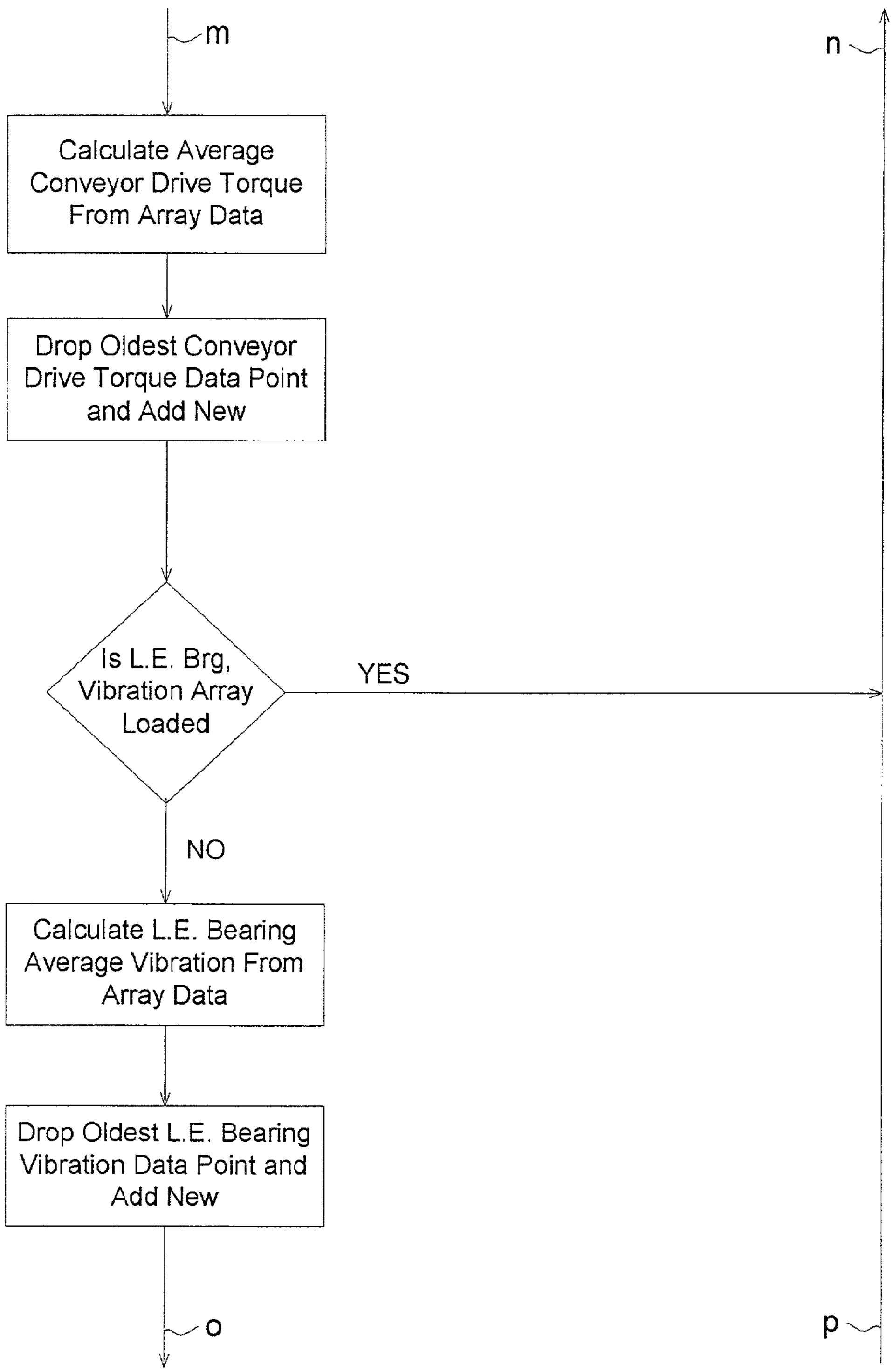

m
n
Calculate Average Conveyor Drive Torque From Array Data
Drop Oldest Conveyor Drive Torque Data Point and Add New
Is L.E. Brg, Vibration Array Loaded
YES
NO
Calculate L.E. Bearing Average Vibration From Array Data
Drop Oldest L.E. Bearing Vibration Data Point and Add New
o
p

FIG 9

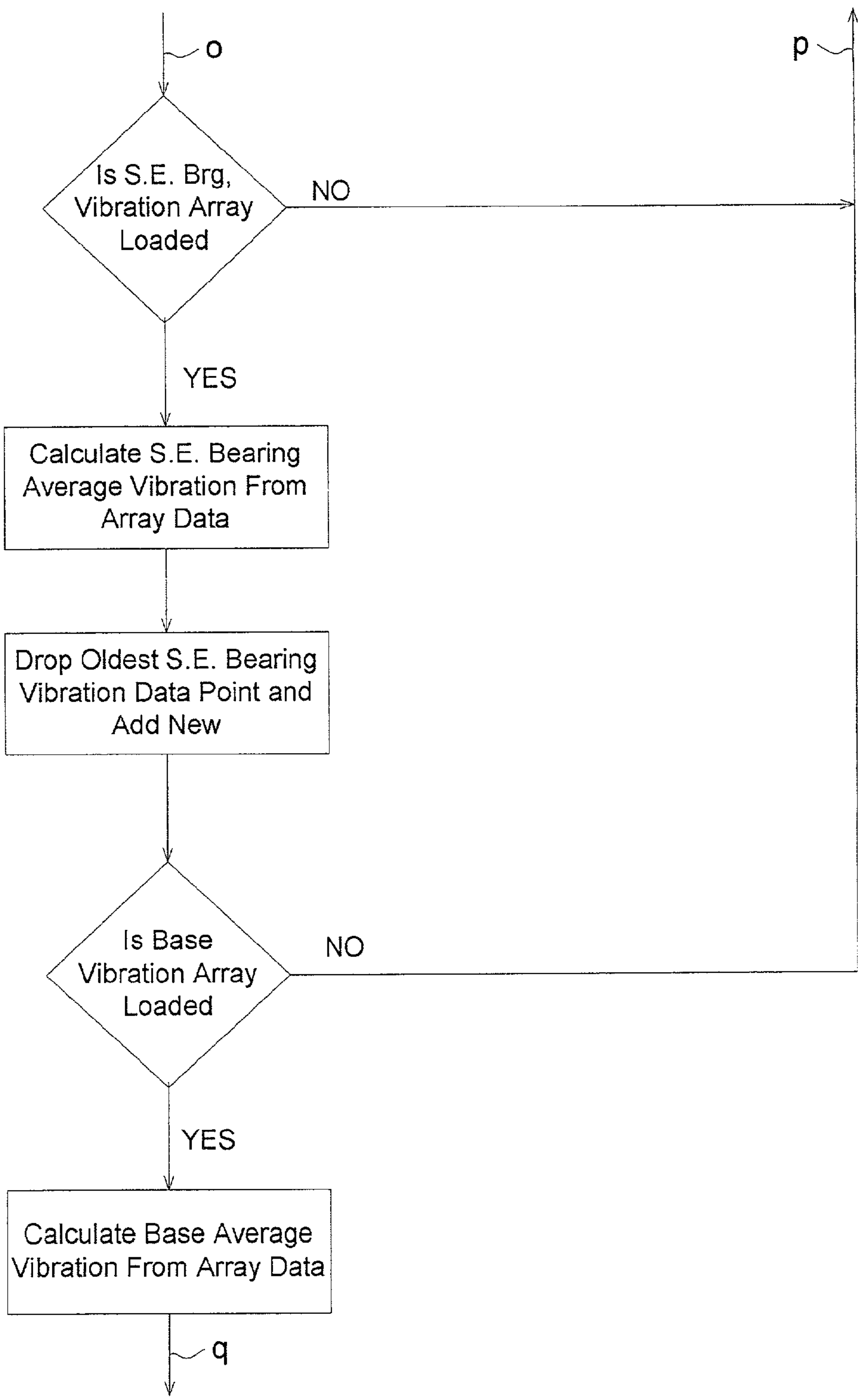

o
p
Is S.E. Brg, Vibration Array Loaded
NO
YES
Calculate S.E. Bearing Average Vibration From Array Data
Drop Oldest S.E. Bearing Vibration Data Point and Add New
Is Base Vibration Array Loaded
NO
YES
Calculate Base Average Vibration From Array Data
q

FIG 10

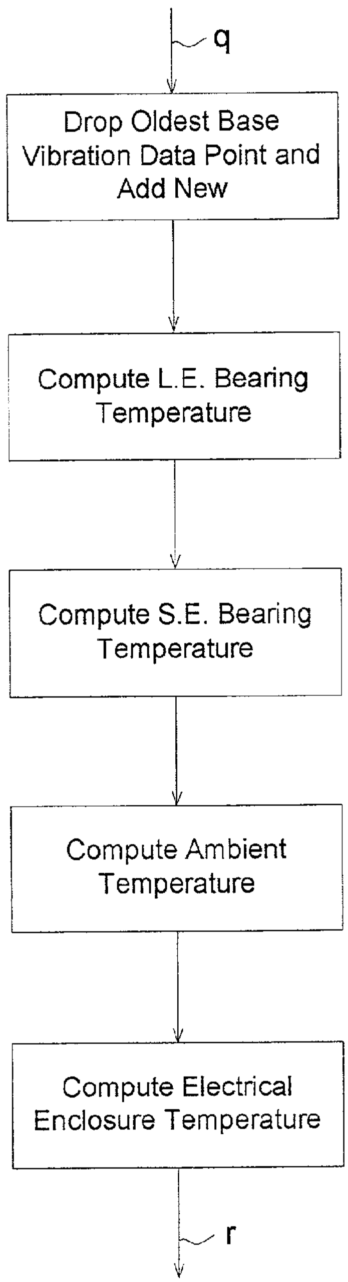

q
Drop Oldest Base Vibration Data Point and Add New
Compute L.E. Bearing Temperature
Compute S.E. Bearing Temperature
Compute Ambient Temperature
Compute Electrical Enclosure Temperature
r

FIG 11

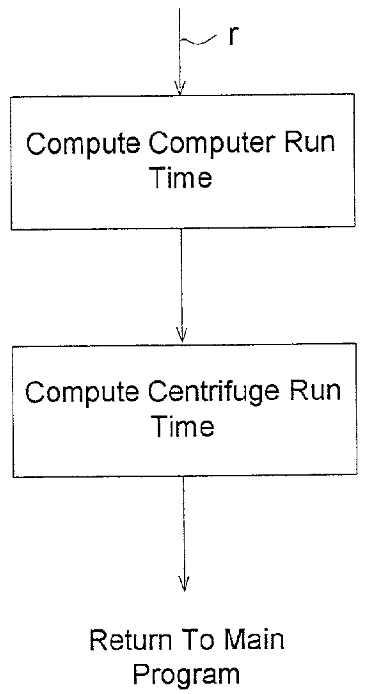

r
Compute Computer Run Time
Compute Centrifuge Run Time
Return To Main Program

FIG 12

ALARM AND SHUTDOWN SUBROUTINE

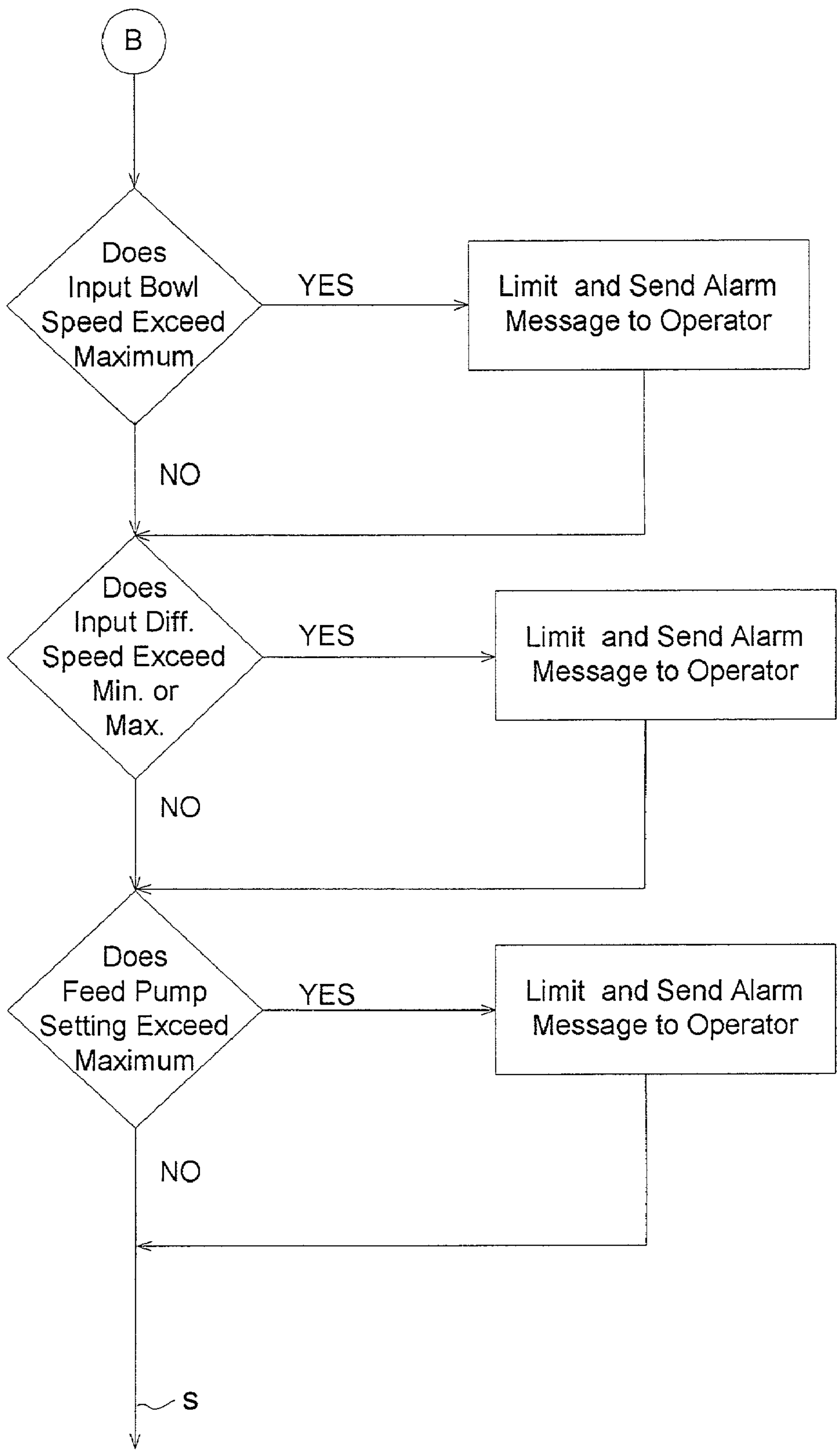


FIG 13

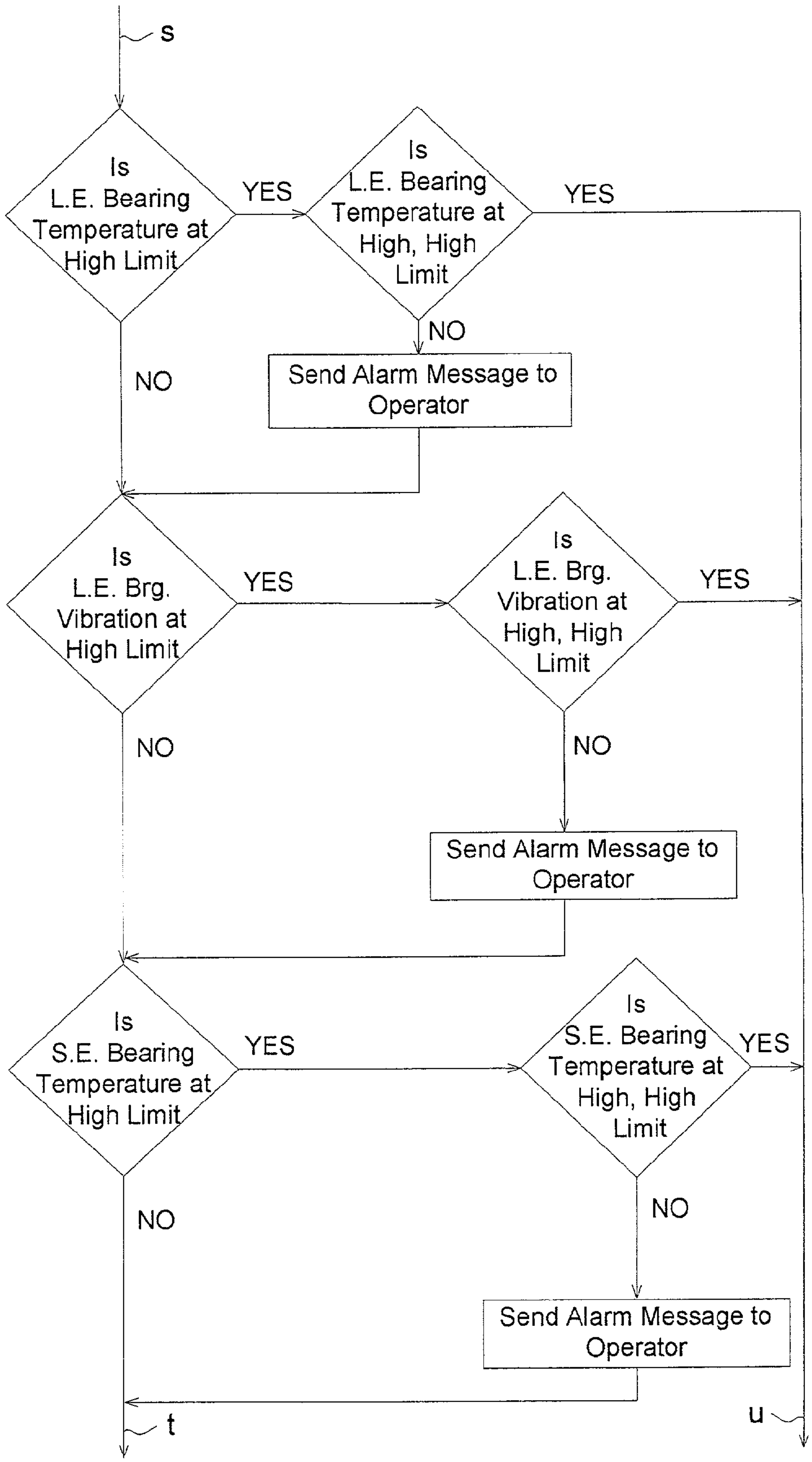

s
Is L.E. Bearing Temperature at High Limit
YES
Is L.E. Bearing Temperature at High, High Limit
YES
NO
Send Alarm Message to Operator
NO
Is L.E. Brg. Vibration at High Limit
YES
Is L.E. Brg. Vibration at High, High Limit
YES
NO
Send Alarm Message to Operator
NO
Is S.E. Bearing Temperature at High Limit
YES
Is S.E. Bearing Temperature at High, High Limit
YES
NO
Send Alarm Message to Operator
NO
t
u

FIG 14

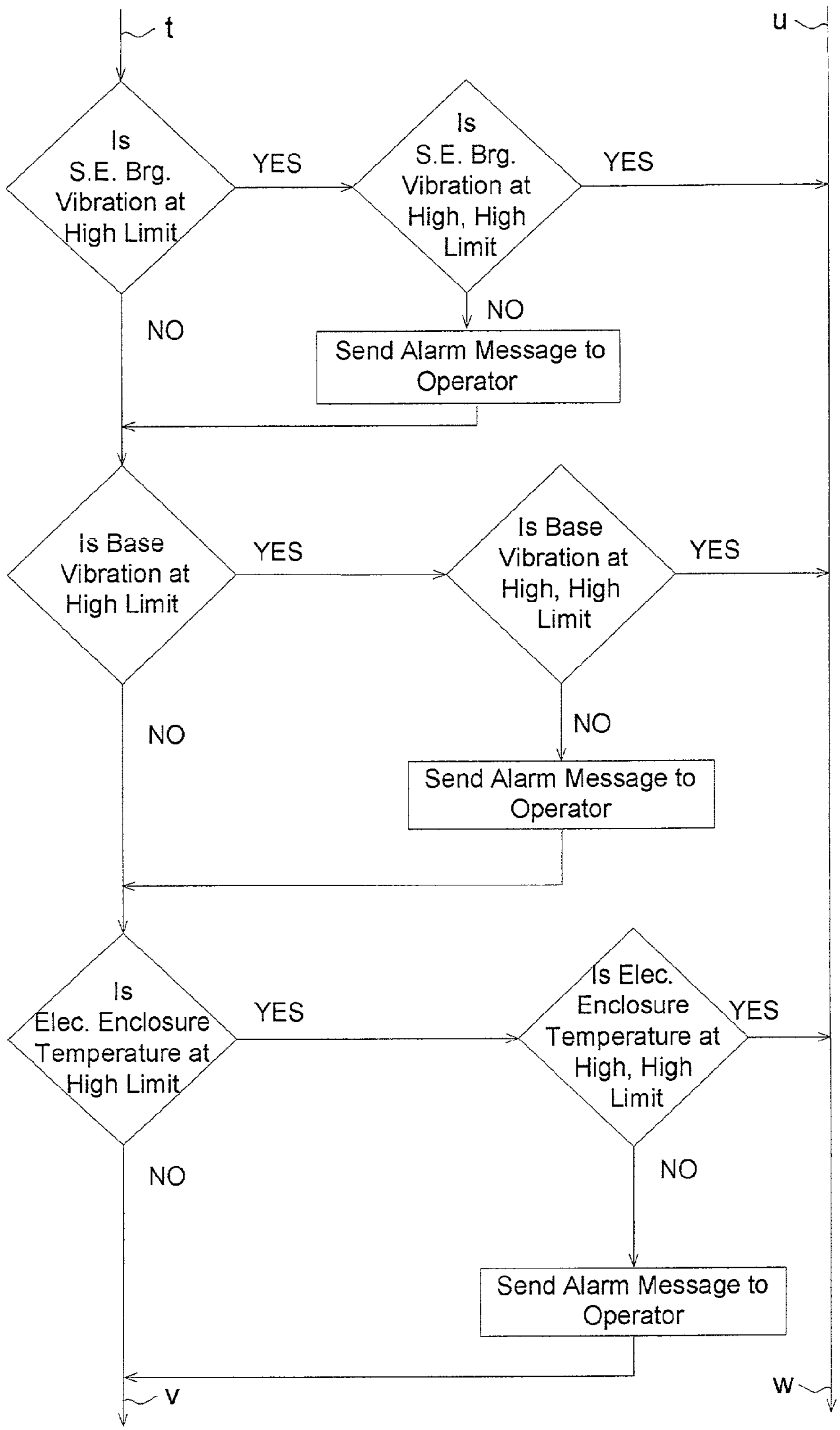

t
u
Is S.E. Brg. Vibration at High Limit
YES
Is S.E. Brg. Vibration at High, High Limit
YES
NO
NO
Send Alarm Message to Operator
Is Base Vibration at High Limit
YES
Is Base Vibration at High, High Limit
YES
NO
NO
Send Alarm Message to Operator
Is Elec. Enclosure Temperature at High Limit
YES
Is Elec. Enclosure Temperature at High, High Limit
YES
NO
NO
Send Alarm Message to Operator
v
w

FIG 15

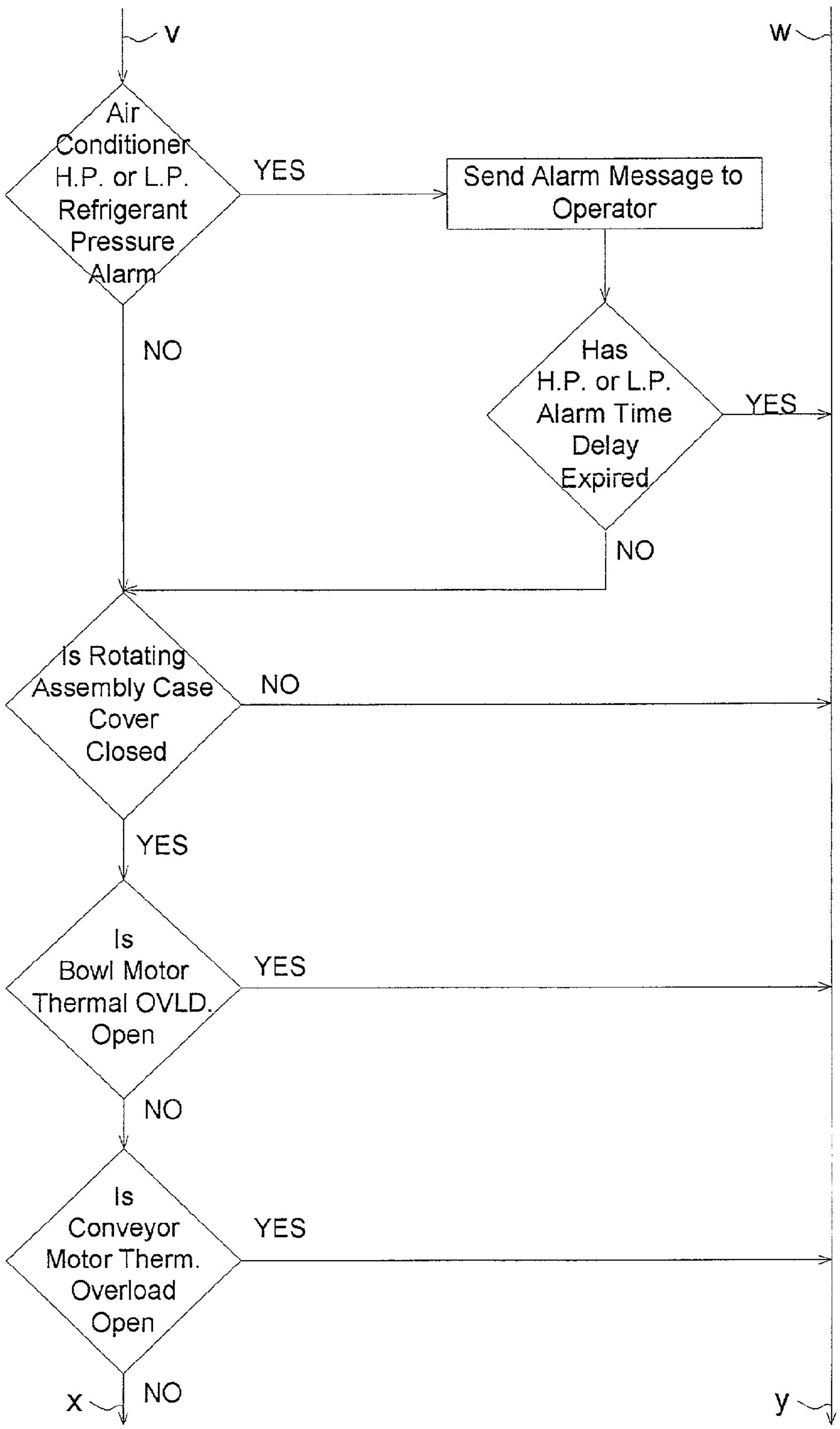

v
w
Air Conditioner H.P. or L.P. Refrigerant Pressure Alarm
YES
Send Alarm Message to Operator
NO
Has H.P. or L.P. Alarm Time Delay Expired
YES
NO
Is Rotating Assembly Case Cover Closed
NO
YES
Is Bowl Motor Thermal OVLD. Open
YES
NO
Is Conveyor Motor Therm. Overload Open
YES
x
NO
y

FIG 16

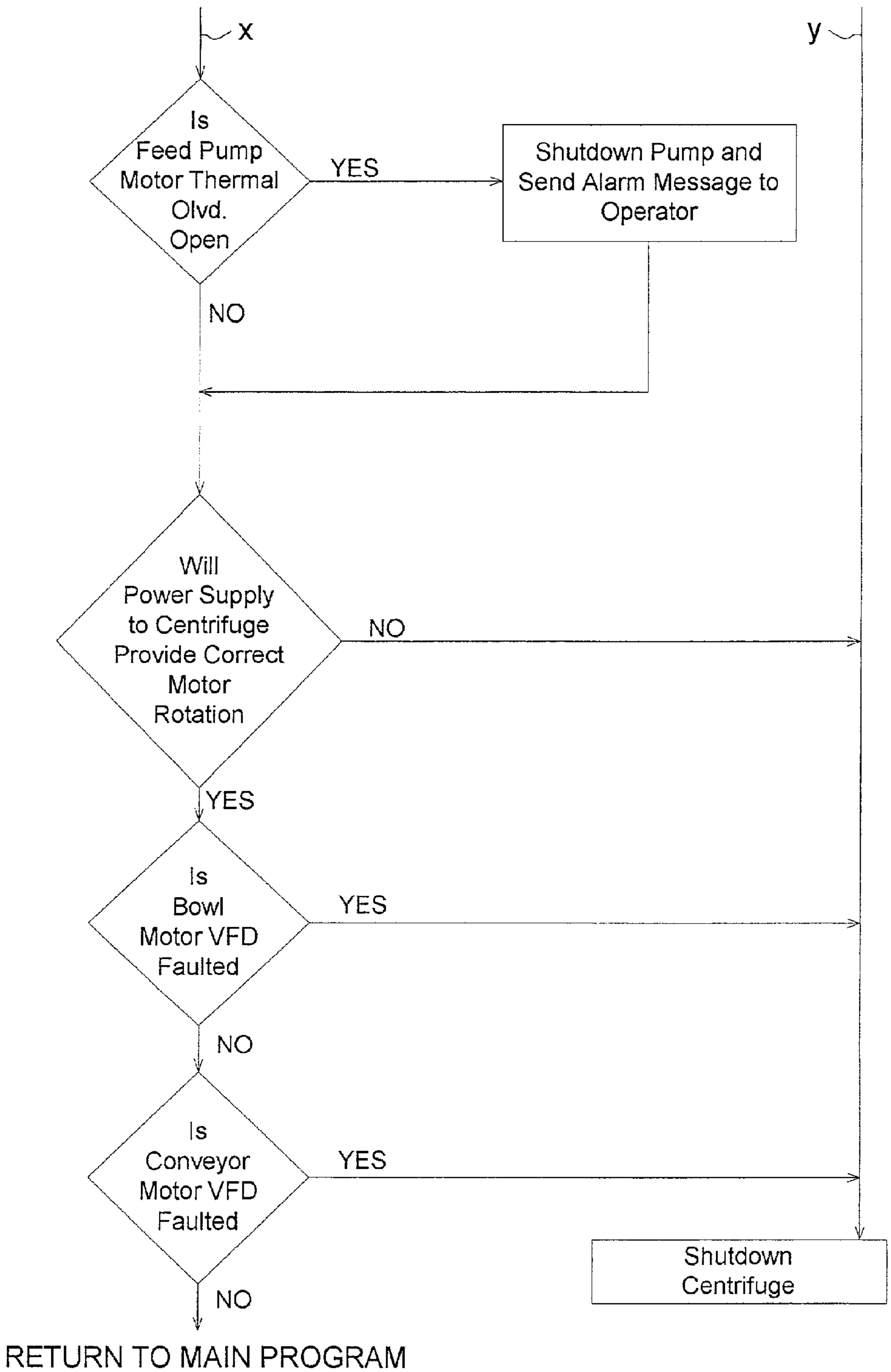

x
y
Is Feed Pump Motor Thermal Olvd. Open
YES
Shutdown Pump and Send Alarm Message to Operator
NO
Will Power Supply to Centrifuge Provide Correct Motor Rotation
NO
YES
Is Bowl Motor VFD Faulted
YES
NO
Is Conveyor Motor VFD Faulted
YES
NO
Shutdown Centrifuge
RETURN TO MAIN PROGRAM

FIG 17

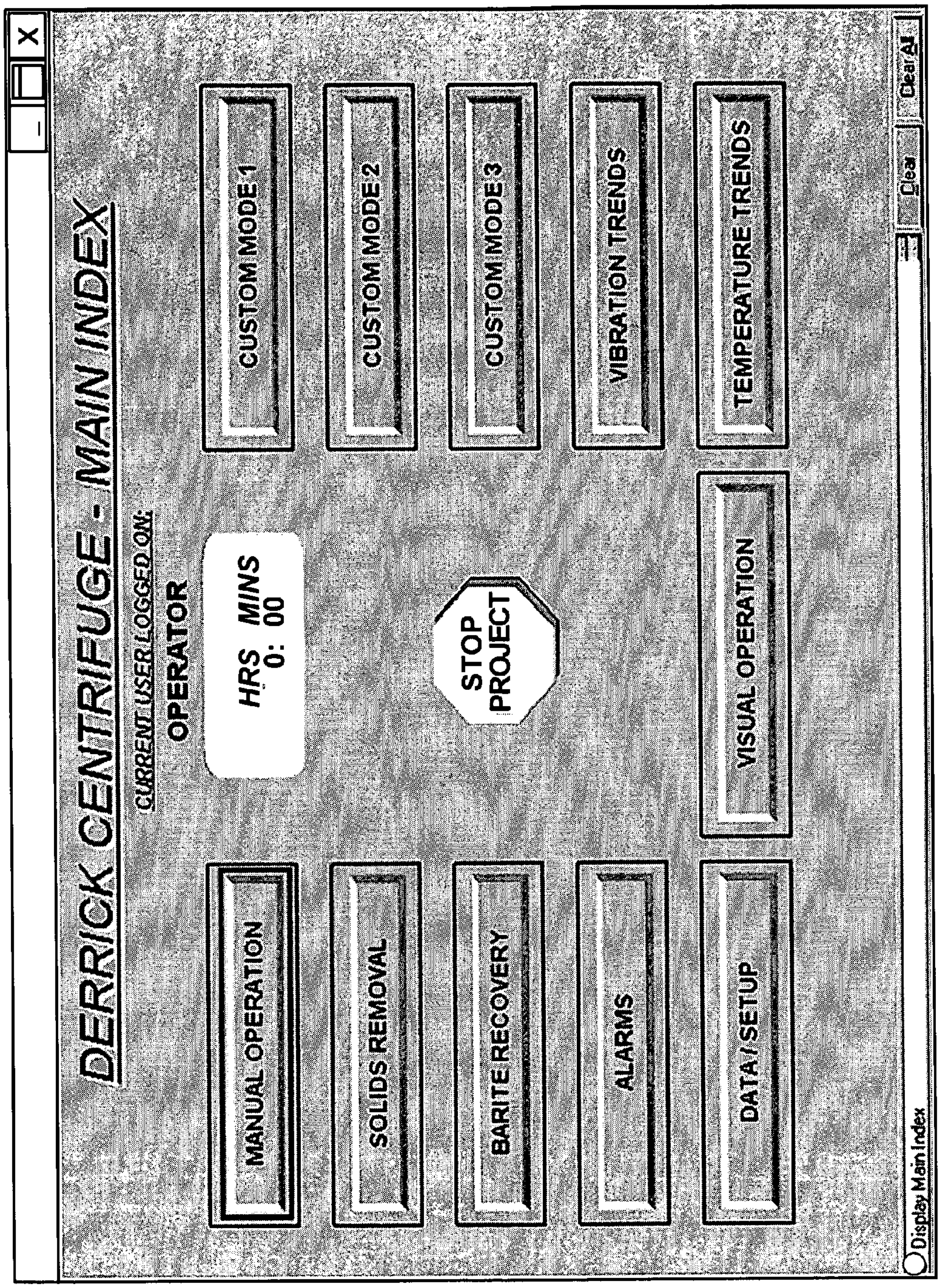

DERRICK CENTRIFUGE - MAIN INDEX
CURRENT USER LOGGED ON:
OPERATOR
HRS MINS
0: 00
STOP PROJECT
MANUAL OPERATION
SOLIDS REMOVAL
BARITE RECOVERY
ALARMS
DATA / SETUP
VISUAL OPERATION
CUSTOM MODE 1
CUSTOM MODE 2
CUSTOM MODE 3
VIBRATION TRENDS
TEMPERATURE TRENDS
Display Main Index
Clear
Clear All

Fig. 18

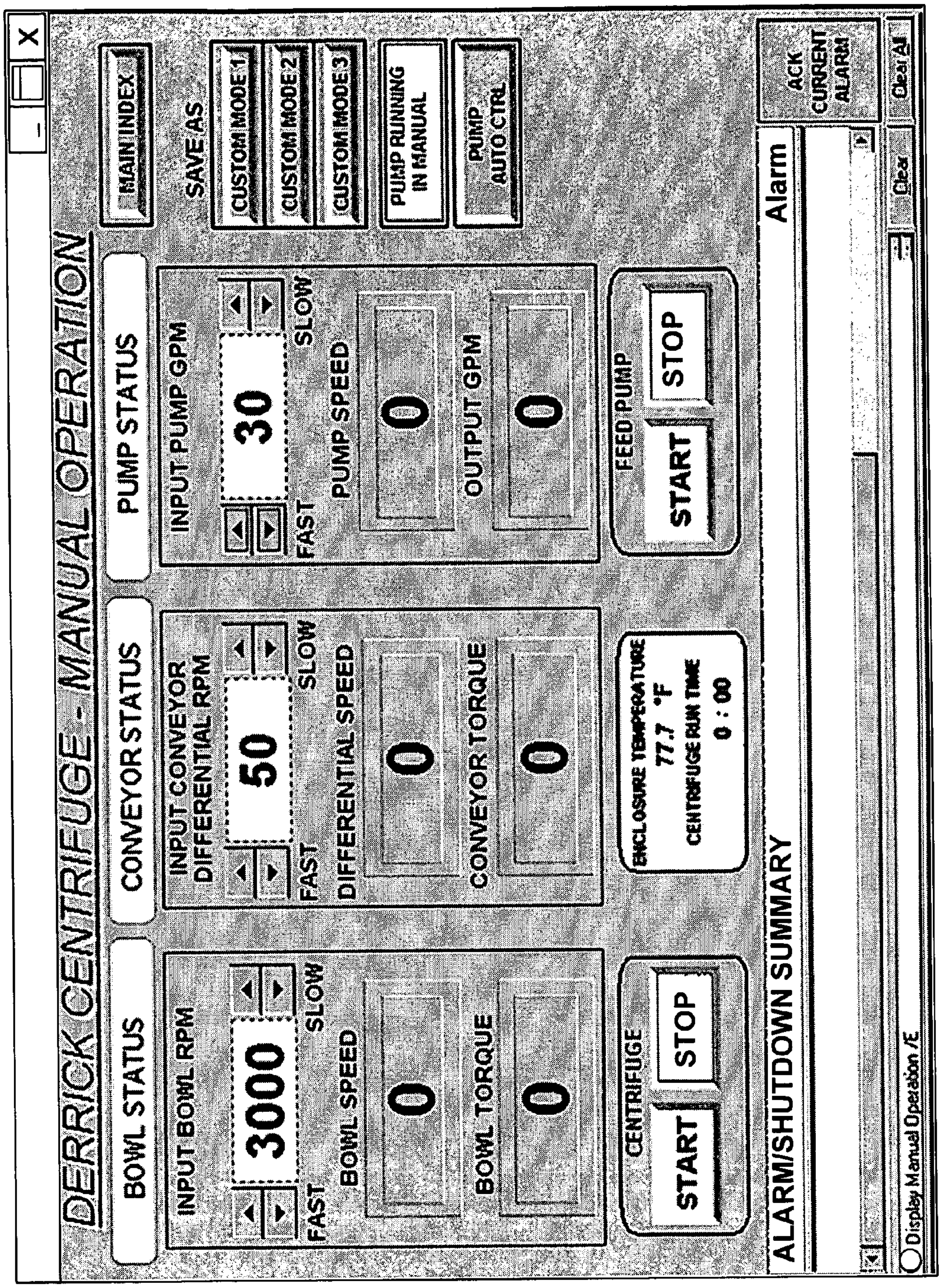

DERRICK CENTRIFUGE - MANUAL OPERATION
BOWL STATUS
INPUT BOWL RPM
3000
FAST
SLOW
BOWL SPEED
0
BOWL TORQUE
0
CENTRIFUGE
START
STOP
CONVEYOR STATUS
INPUT CONVEYOR DIFFERENTIAL RPM
50
FAST
SLOW
DIFFERENTIAL SPEED
0
CONVEYOR TORQUE
0
ENCLOSURE TEMPERATURE
77.7 °F
CENTRIFUGE RUN TIME
0 : 00
PUMP STATUS
INPUT PUMP GPM
30
FAST
SLOW
PUMP SPEED
0
OUTPUT GPM
0
FEED PUMP
START
STOP
MAIN INDEX
SAVE AS
CUSTOM MODE 1
CUSTOM MODE 2
CUSTOM MODE 3
PUMP RUNNING IN MANUAL
PUMP AUTO CTRL
ALARM/SHUTDOWN SUMMARY
Alarm
ACK CURRENT ALARM
Clear
Clear All
Display Manual Operation /E

Fig. 19

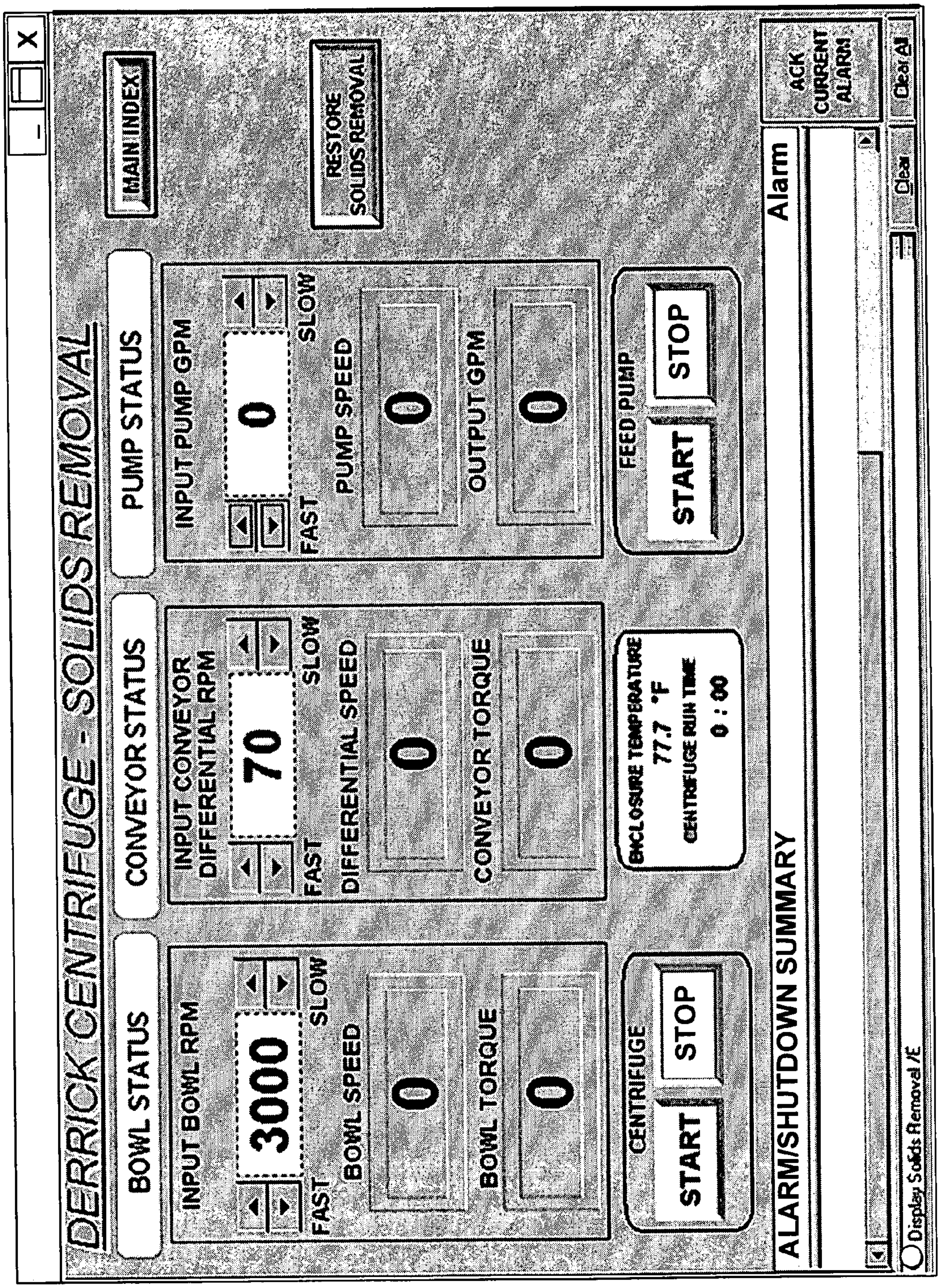

DERRICK CENTRIFUGE - SOLIDS REMOVAL
BOWL STATUS
CONVEYOR STATUS
PUMP STATUS
MAIN INDEX
RESTORE SOLIDS REMOVAL
INPUT BOWL RPM
3000
FAST
SLOW
BOWL SPEED
0
BOWL TORQUE
0
CENTRIFUGE
START
STOP
INPUT CONVEYOR DIFFERENTIAL RPM
70
FAST
SLOW
DIFFERENTIAL SPEED
0
CONVEYOR TORQUE
0
ENCLOSURE TEMPERATURE
77.7 °F
CENTRIFUGE RUN TIME
0 : 00
INPUT PUMP GPM
0
FAST
SLOW
PUMP SPEED
0
OUTPUT GPM
0
FEED PUMP
START
STOP
ALARM/SHUTDOWN SUMMARY
Alarm
ACK CURRENT ALARM
Clear
Clear All
Display Solids Removal /E

Fig. 20

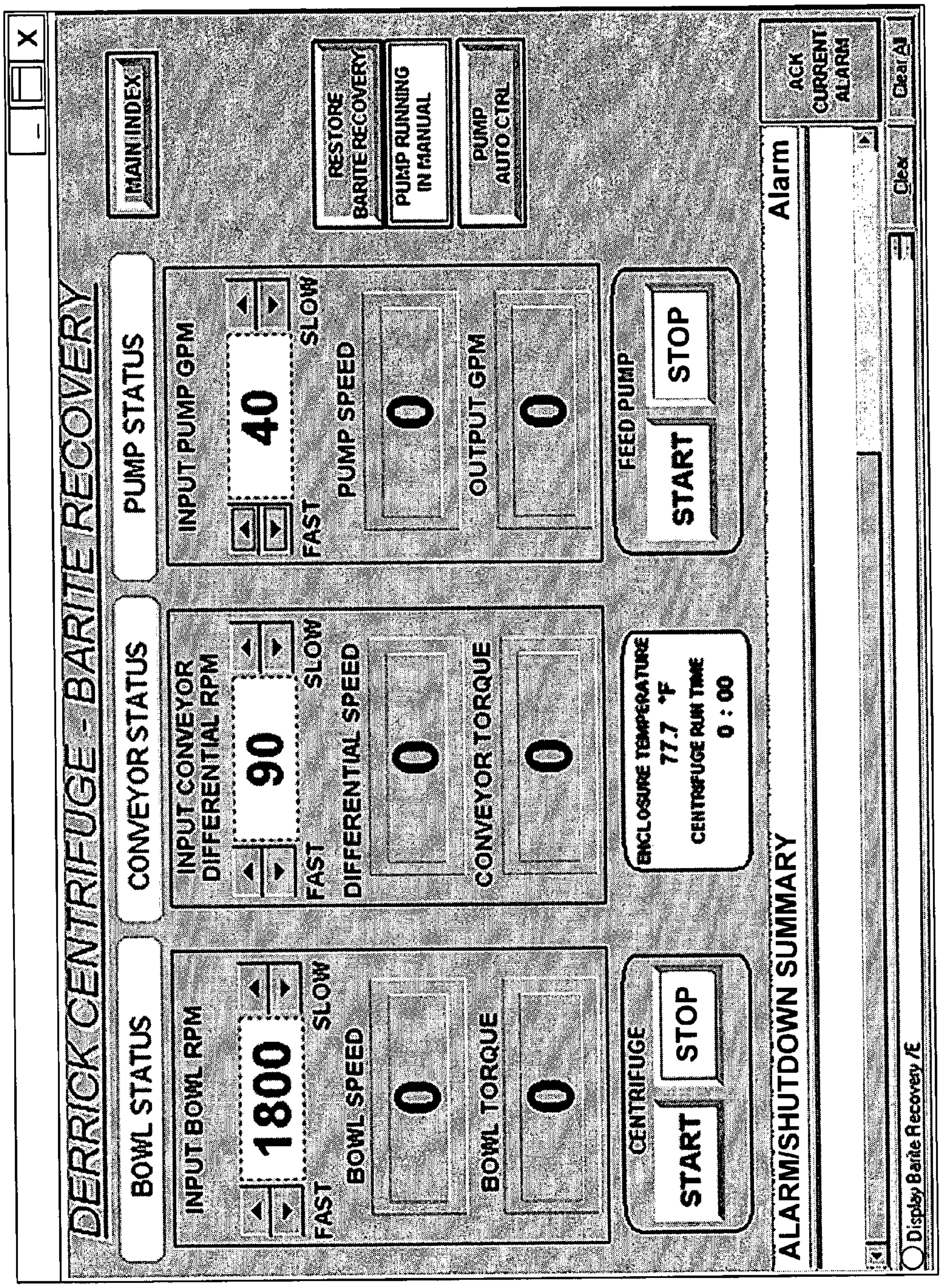

DERRICK CENTRIFUGE - BARITE RECOVERY
BOWL STATUS
INPUT BOWL RPM
1800
FAST
SLOW
BOWL SPEED
0
BOWL TORQUE
0
CONVEYOR STATUS
INPUT CONVEYOR DIFFERENTIAL RPM
90
FAST
SLOW
DIFFERENTIAL SPEED
0
CONVEYOR TORQUE
0
PUMP STATUS
INPUT PUMP GPM
40
FAST
SLOW
PUMP SPEED
0
OUTPUT GPM
0
MAIN INDEX
RESTORE BARITE RECOVERY
PUMP RUNNING IN MANUAL
PUMP AUTO CTRL
CENTRIFUGE
START
STOP
ENCLOSURE TEMPERATURE
77.7 °F
CENTRIFUGE RUN TIME
0 : 00
FEED PUMP
START
STOP
ALARM/SHUTDOWN SUMMARY
Alarm
ACK CURRENT ALARM
Clear
Clear All
Display Barite Recovery /E

Fig. 21

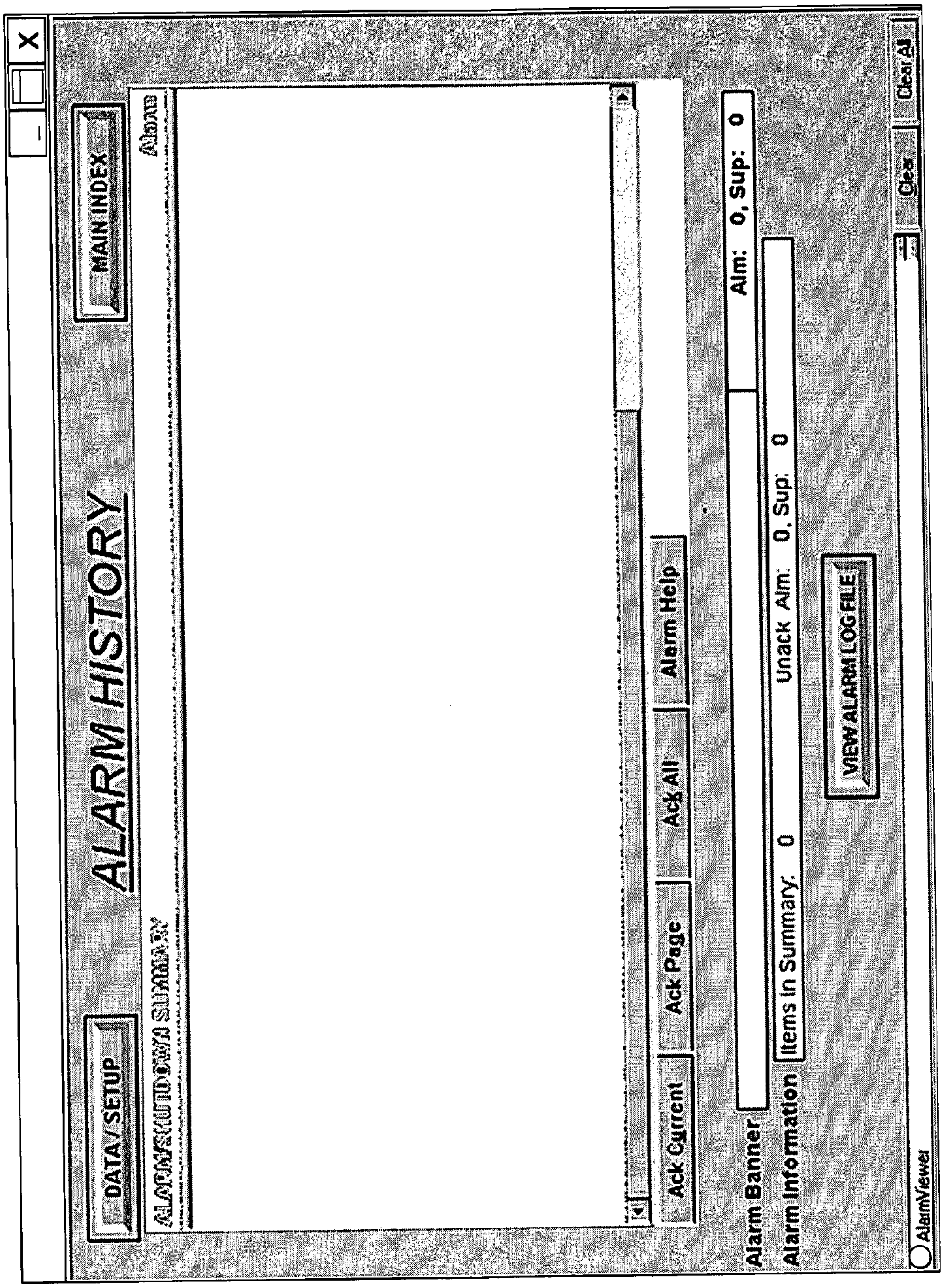

ALARM HISTORY
DATA / SETUP
MAIN INDEX
Alarm
Ack Current
Ack Page
Ack All
Alarm Help
Alarm Banner
Alm: 0, Sup: 0
Alarm Information
Items In Summary: 0
Unack Alm: 0, Sup: 0
VIEW ALARM LOG FILE
Clear
Clear All
AlarmViewer

Fig. 22

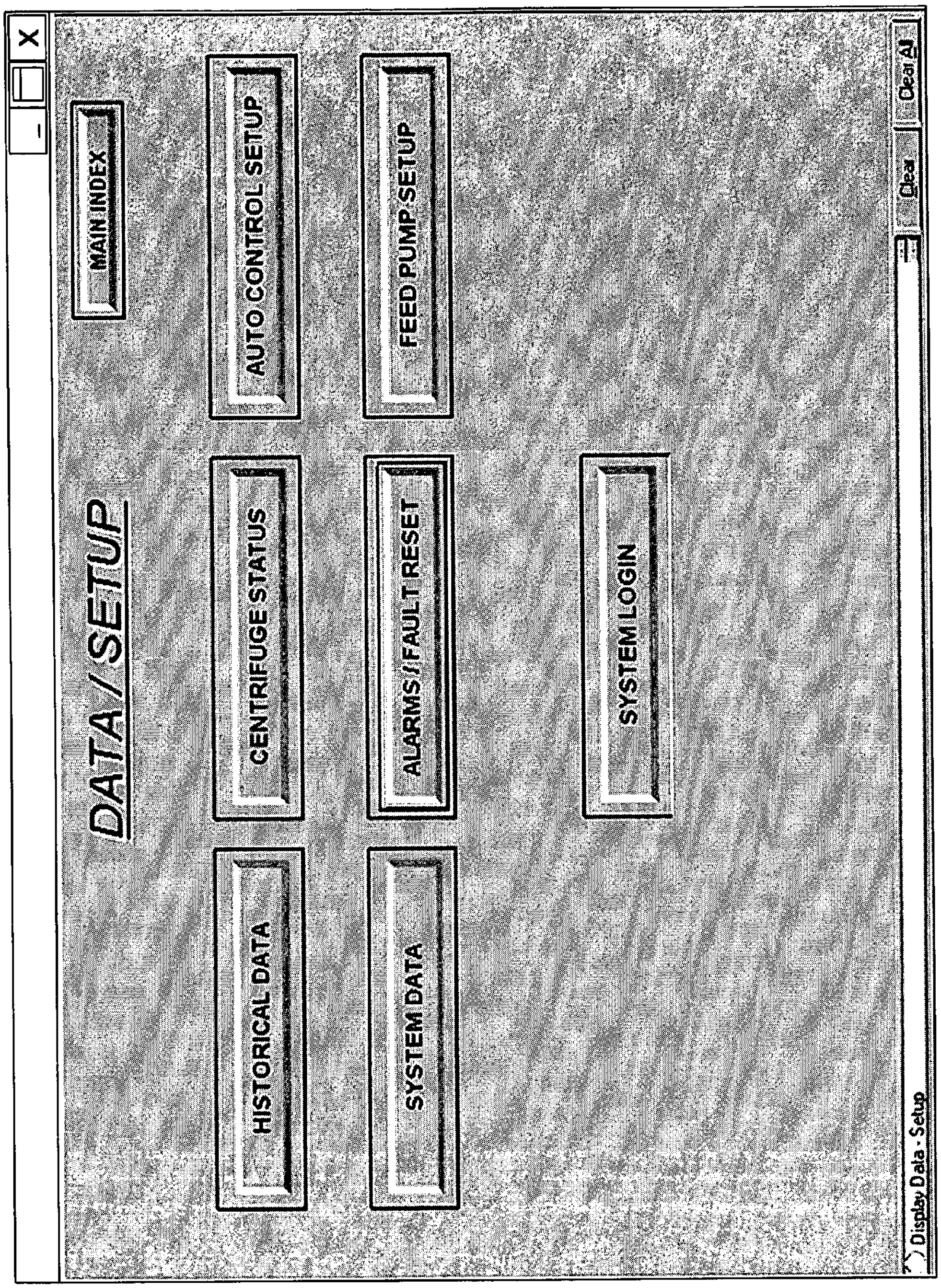

DATA / SETUP
MAIN INDEX
AUTO CONTROL SETUP
FEED PUMP SETUP
CENTRIFUGE STATUS
ALARMS / FAULT RESET
SYSTEM LOGIN
HISTORICAL DATA
SYSTEM DATA
Display Data - Setup
Clear
Clear All

Fig. 23

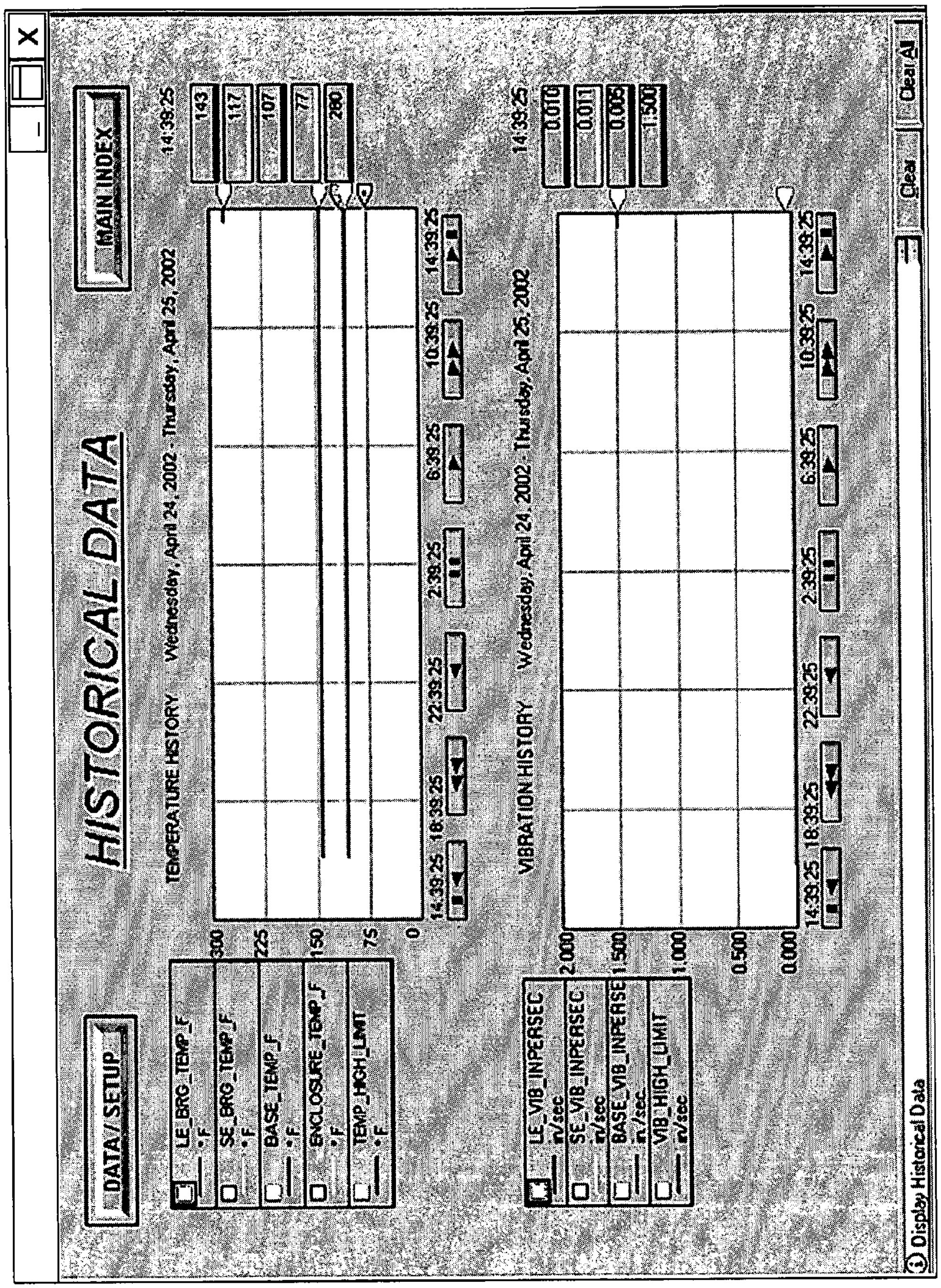

HISTORICAL DATA
MAIN INDEX
DATA / SETUP
TEMPERATURE HISTORY
Wednesday, April 24, 2002 - Thursday, April 25, 2002
LE_BRG_TEMP_F
SE_BRG_TEMP_F
BASE_TEMP_F
ENCLOSURE_TEMP_F
TEMP_HIGH_LIMIT
300
225
150
75
0
143
117
107
77
280
14:39:25
18:39:25
22:39:25
2:39:25
6:39:25
10:39:25
VIBRATION HISTORY
LE_VIB_INPERSEC
SE_VIB_INPERSEC
BASE_VIB_INPERSE
VIB_HIGH_LIMIT
in/sec
2.000
1.500
1.000
0.500
0.000
0.010
0.011
0.005
1.500
Clear
Clear All
Display Historical Data

Fig. 24

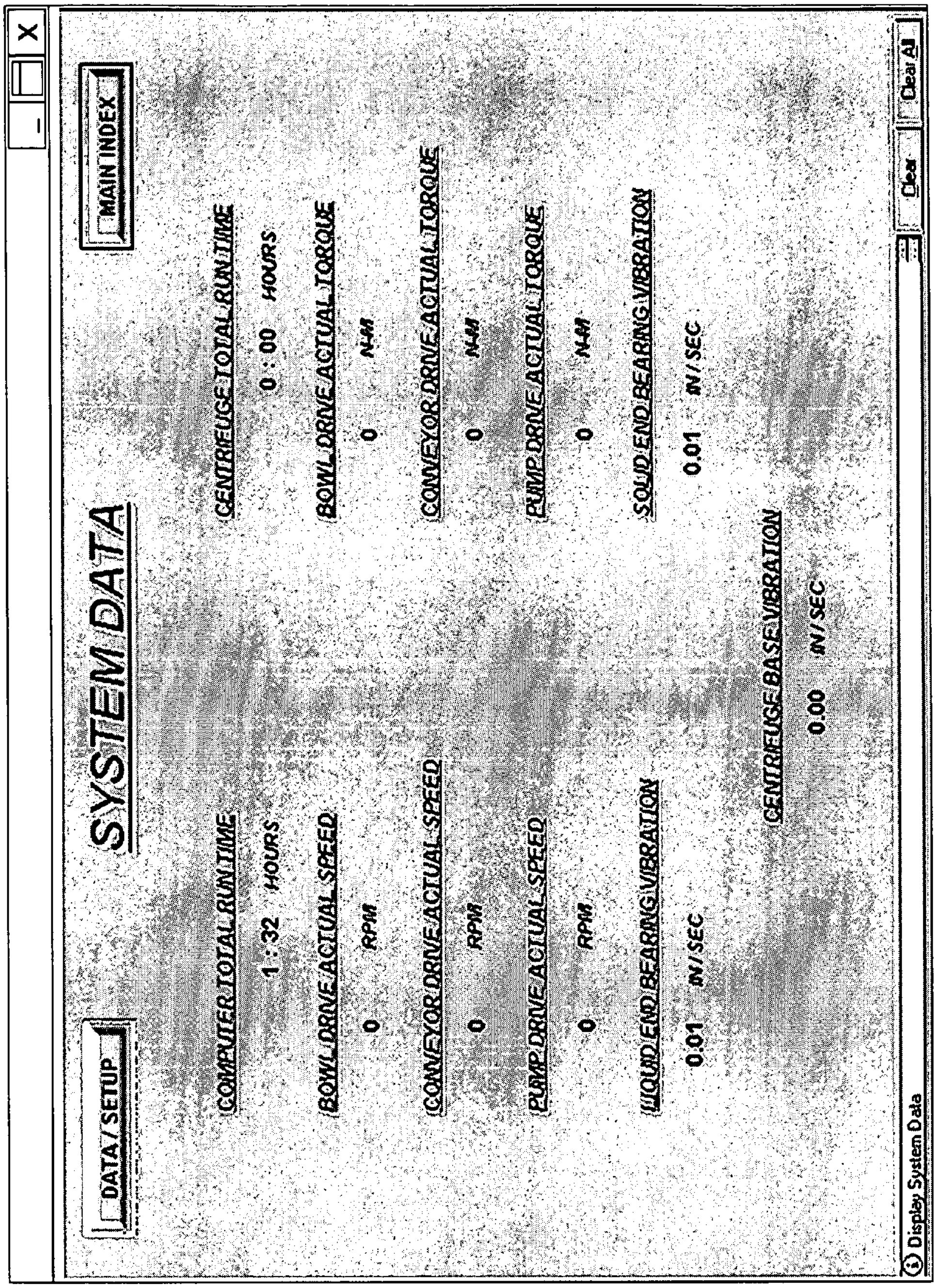

DATA / SETUP
SYSTEM DATA
MAIN INDEX
COMPUTER TOTAL RUN TIME
1 : 32 HOURS
CENTRIFUGE TOTAL RUN TIME
0 : 00 HOURS
BOWL DRIVE ACTUAL SPEED
0 RPM
BOWL DRIVE ACTUAL TORQUE
0 N-M
CONVEYOR DRIVE ACTUAL SPEED
0 RPM
CONVEYOR DRIVE ACTUAL TORQUE
0 N-M
PUMP DRIVE ACTUAL SPEED
0 RPM
PUMP DRIVE ACTUAL TORQUE
0 N-M
LIQUID END BEARING VIBRATION
0.01 IN / SEC
SOLID END BEARING VIBRATION
0.01 IN / SEC
CENTRIFUGE BASE VIBRATION
0.00 IN / SEC
Display System Data
Clear
Clear All

Fig. 25

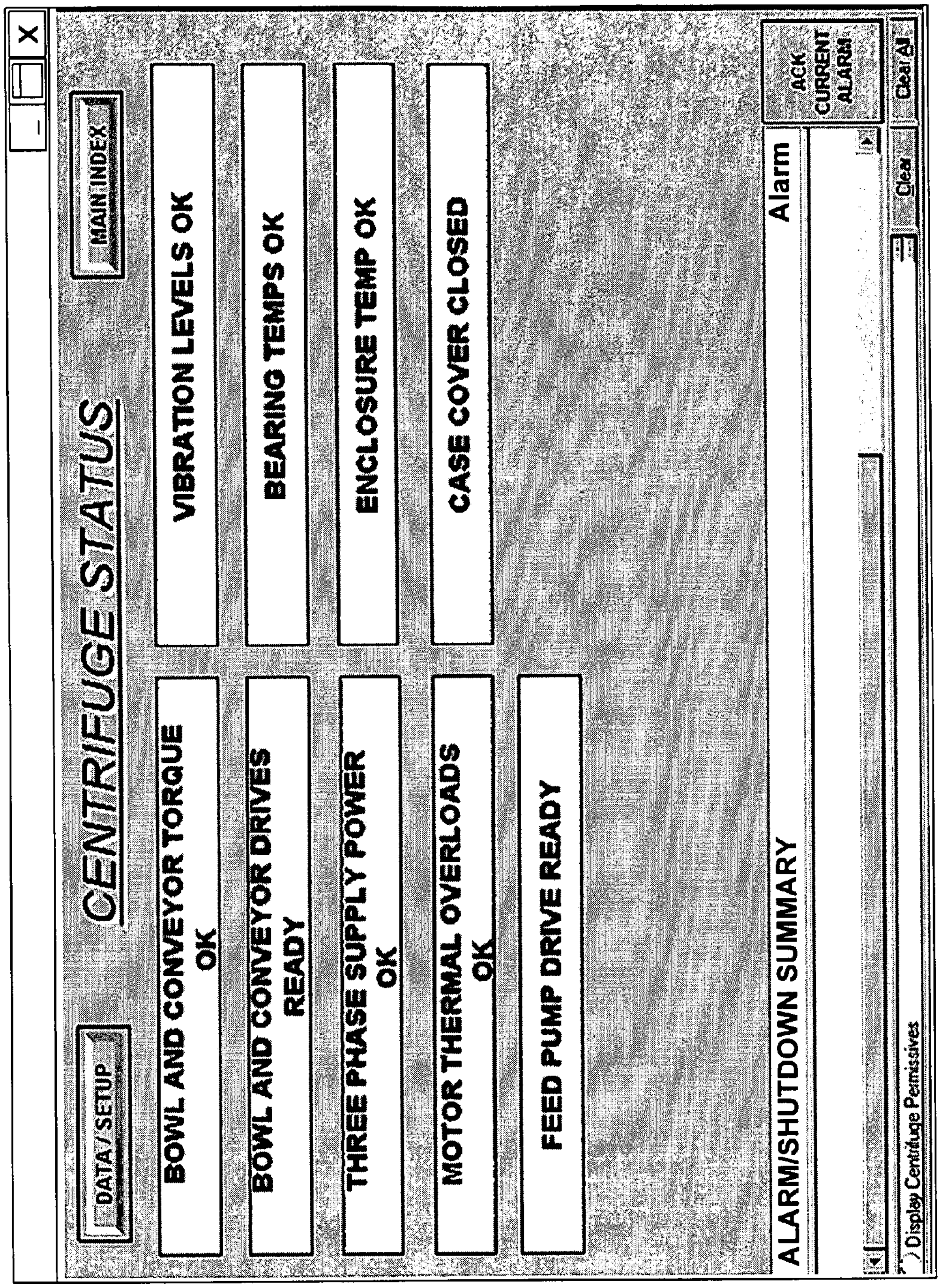

CENTRIFUGE STATUS
DATA / SETUP
MAIN INDEX
BOWL AND CONVEYOR TORQUE OK
VIBRATION LEVELS OK
BOWL AND CONVEYOR DRIVES READY
BEARING TEMPS OK
THREE PHASE SUPPLY POWER OK
ENCLOSURE TEMP OK
MOTOR THERMAL OVERLOADS OK
CASE COVER CLOSED
FEED PUMP DRIVE READY
ALARM/SHUTDOWN SUMMARY
Alarm
ACK CURRENT ALARM
Clear
Clear All
Display Centrifuge Permissives

Fig. 26

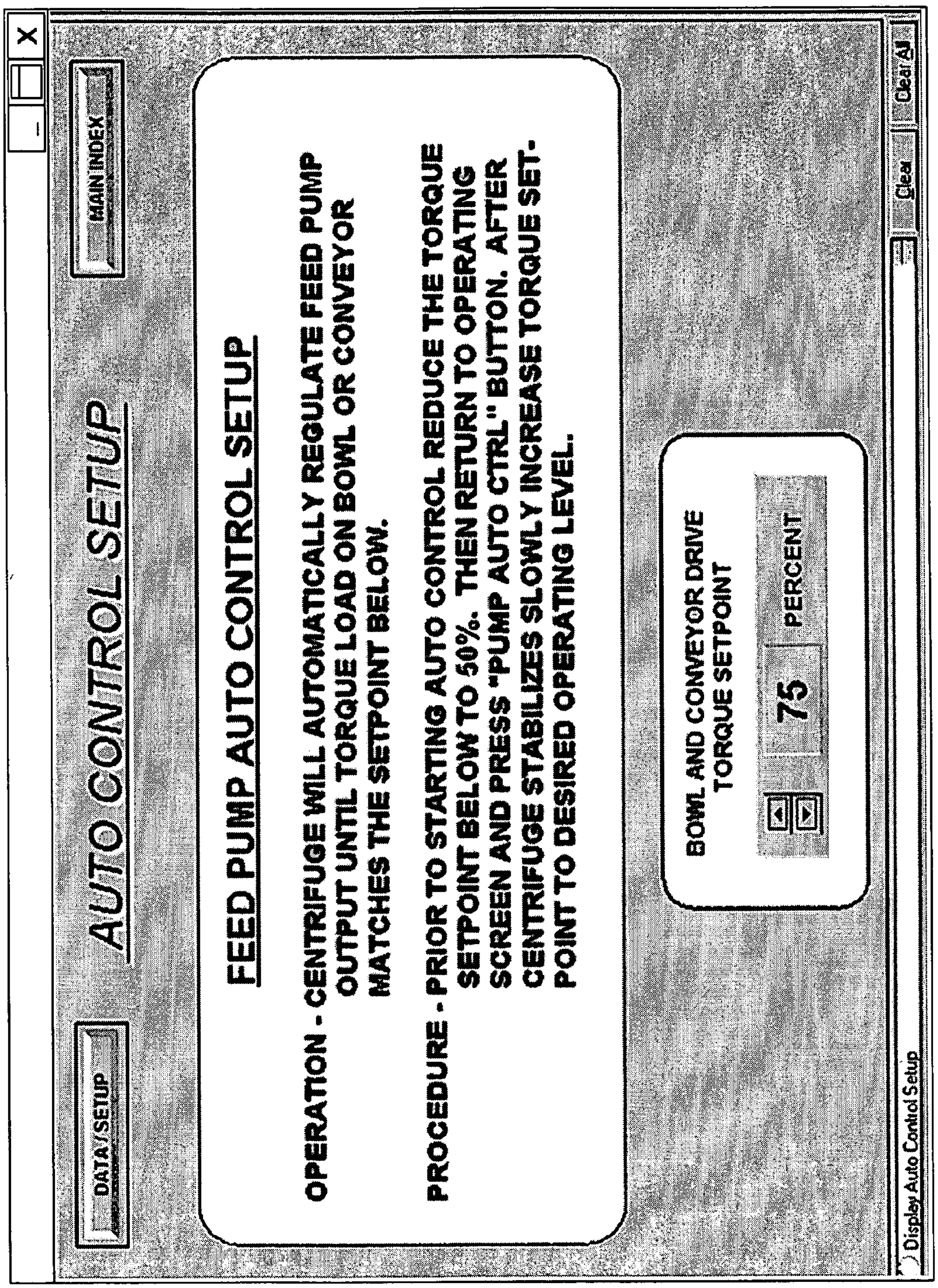

AUTO CONTROL SETUP
DATA / SETUP
MAIN INDEX
FEED PUMP AUTO CONTROL SETUP
OPERATION - CENTRIFUGE WILL AUTOMATICALLY REGULATE FEED PUMP OUTPUT UNTIL TORQUE LOAD ON BOWL OR CONVEYOR MATCHES THE SETPOINT BELOW.
PROCEDURE - PRIOR TO STARTING AUTO CONTROL REDUCE THE TORQUE SETPOINT BELOW TO 50%. THEN RETURN TO OPERATING SCREEN AND PRESS "PUMP AUTO CTRL" BUTTON. AFTER CENTRIFUGE STABILIZIES SLOWLY INCREASE TORQUE SETPOINT TO DESIRED OPERATING LEVEL.
BOWL AND CONVEYOR DRIVE TORQUE SETPOINT
75
PERCENT
Display Auto Control Setup
Clear
Clear All

Fig. 27

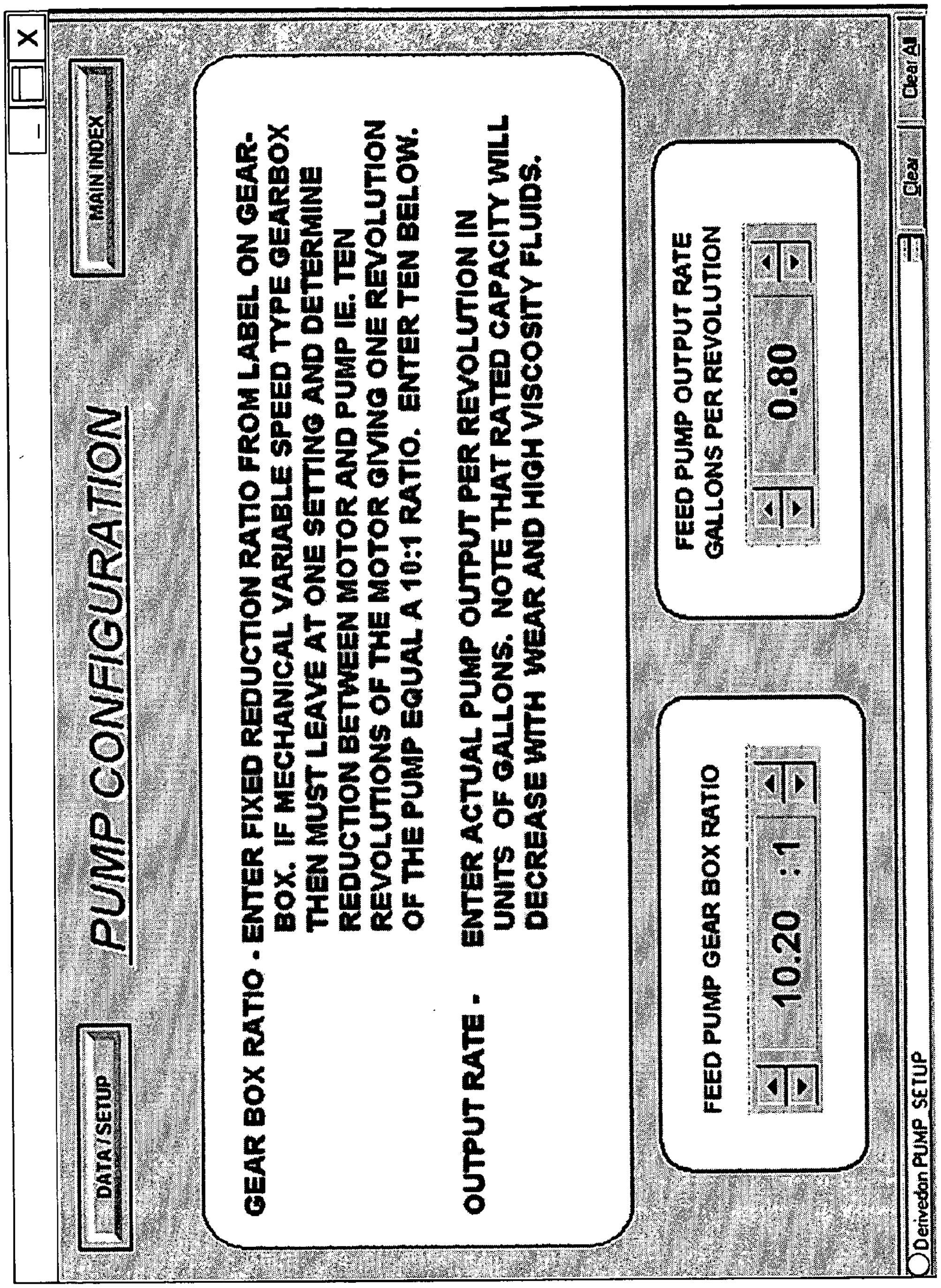

PUMP CONFIGURATION
DATA/SETUP
MAIN INDEX
GEAR BOX RATIO - ENTER FIXED REDUCTION RATIO FROM LABEL ON GEAR-BOX. IF MECHANICAL VARIABLE SPEED TYPE GEARBOX THEN MUST LEAVE AT ONE SETTING AND DETERMINE REDUCTION BETWEEN MOTOR AND PUMP IE. TEN REVOLUTIONS OF THE MOTOR GIVING ONE REVOLUTION OF THE PUMP EQUAL A 10:1 RATIO. ENTER TEN BELOW.
OUTPUT RATE - ENTER ACTUAL PUMP OUTPUT PER REVOLUTION IN UNITS OF GALLONS. NOTE THAT RATED CAPACITY WILL DECREASE WITH WEAR AND HIGH VISCOSITY FLUIDS.
FEED PUMP GEAR BOX RATIO
10.20 :1
FEED PUMP OUTPUT RATE
GALLONS PER REVOLUTION
0.80
Clear
Clear All
Derivedon PUMP SETUP

Fig. 28

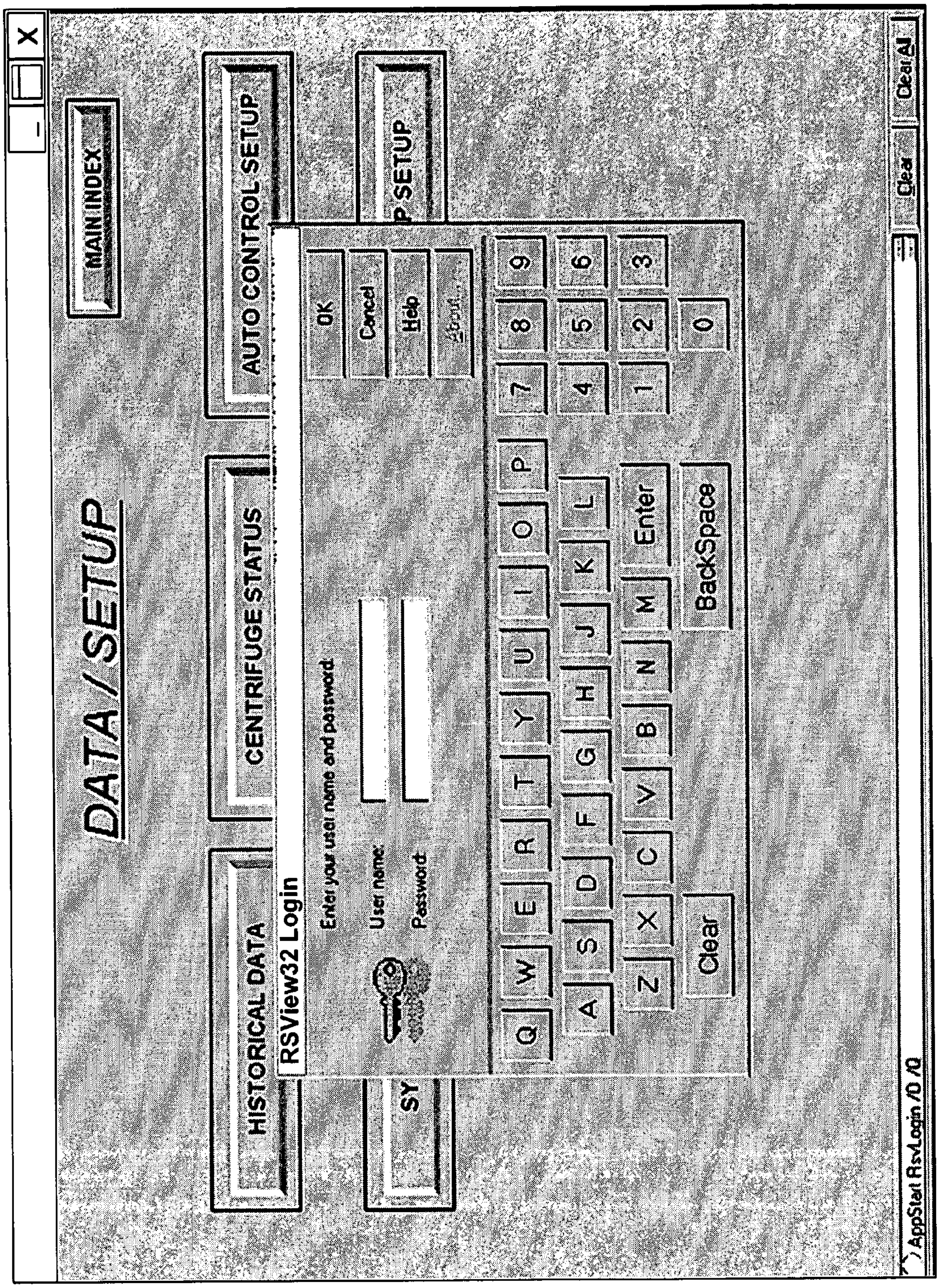

DATA / SETUP
MAIN INDEX
HISTORICAL DATA
CENTRIFUGE STATUS
AUTO CONTROL SETUP
SY
P SETUP
RSView32 Login
Enter your user name and password
User name:
Password:
OK
Cancel
Help
About...
Q W E R T Y U I O P 7 8 9
A S D F G H J K L 4 5 6
Z X C V B N M Enter 1 2 3
Clear BackSpace 0
AppStart RsvLogin /D /Q
Clear
Clear All

Fig. 29

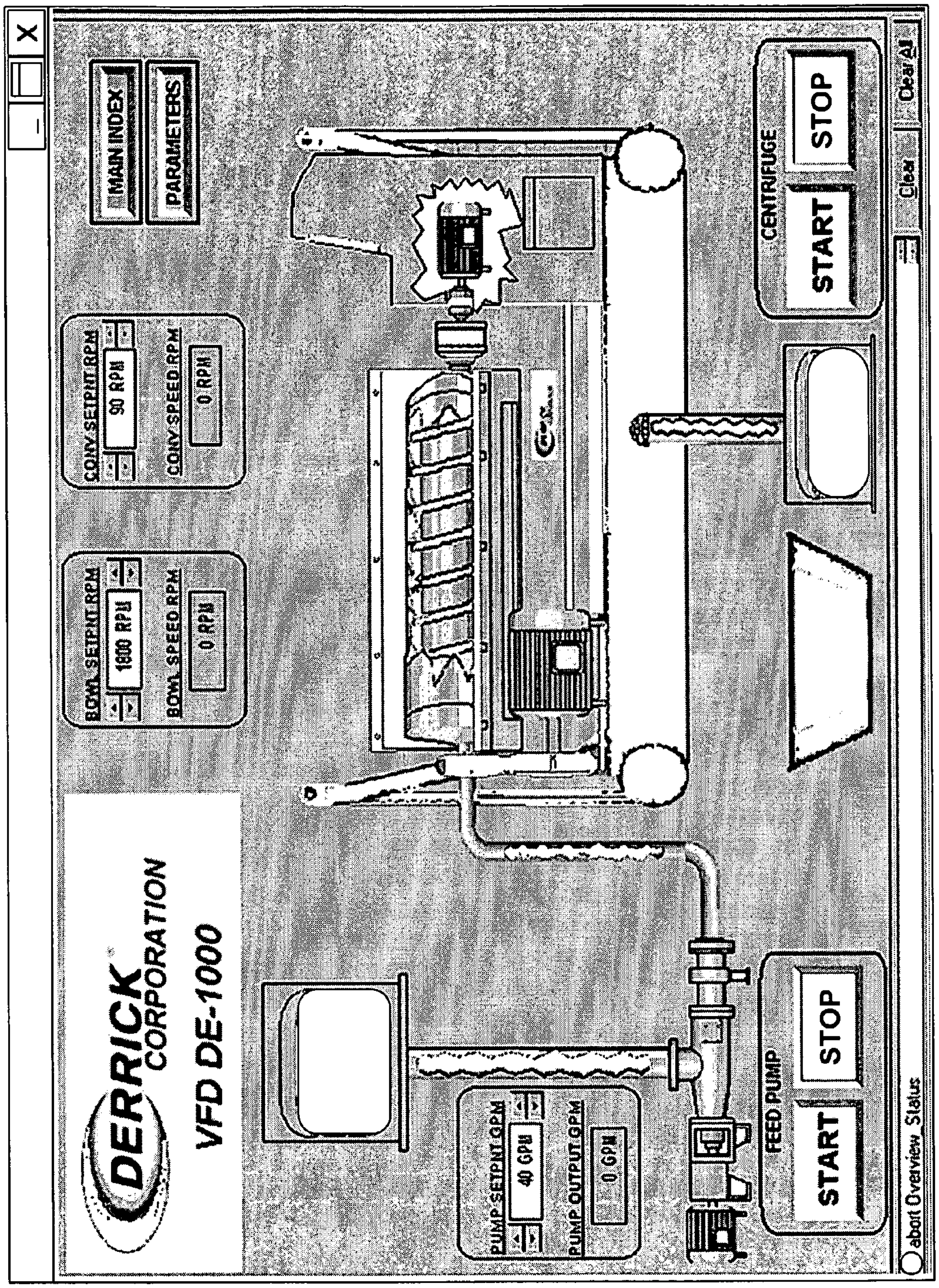

MAIN INDEX
PARAMETERS
CONV. SETPNT RPM
90 RPM
CONV. SPEED RPM
0 RPM
BOWL SETPNT RPM
1800 RPM
BOWL SPEED RPM
0 RPM
DERRICK CORPORATION
VFD DE-1000
PUMP SETPNT GPM
40 GPM
PUMP OUTPUT GPM
0 GPM
FEED PUMP
START
STOP
CENTRIFUGE
START
STOP
Clear
Clear All
abort Overview Status

Fig. 30

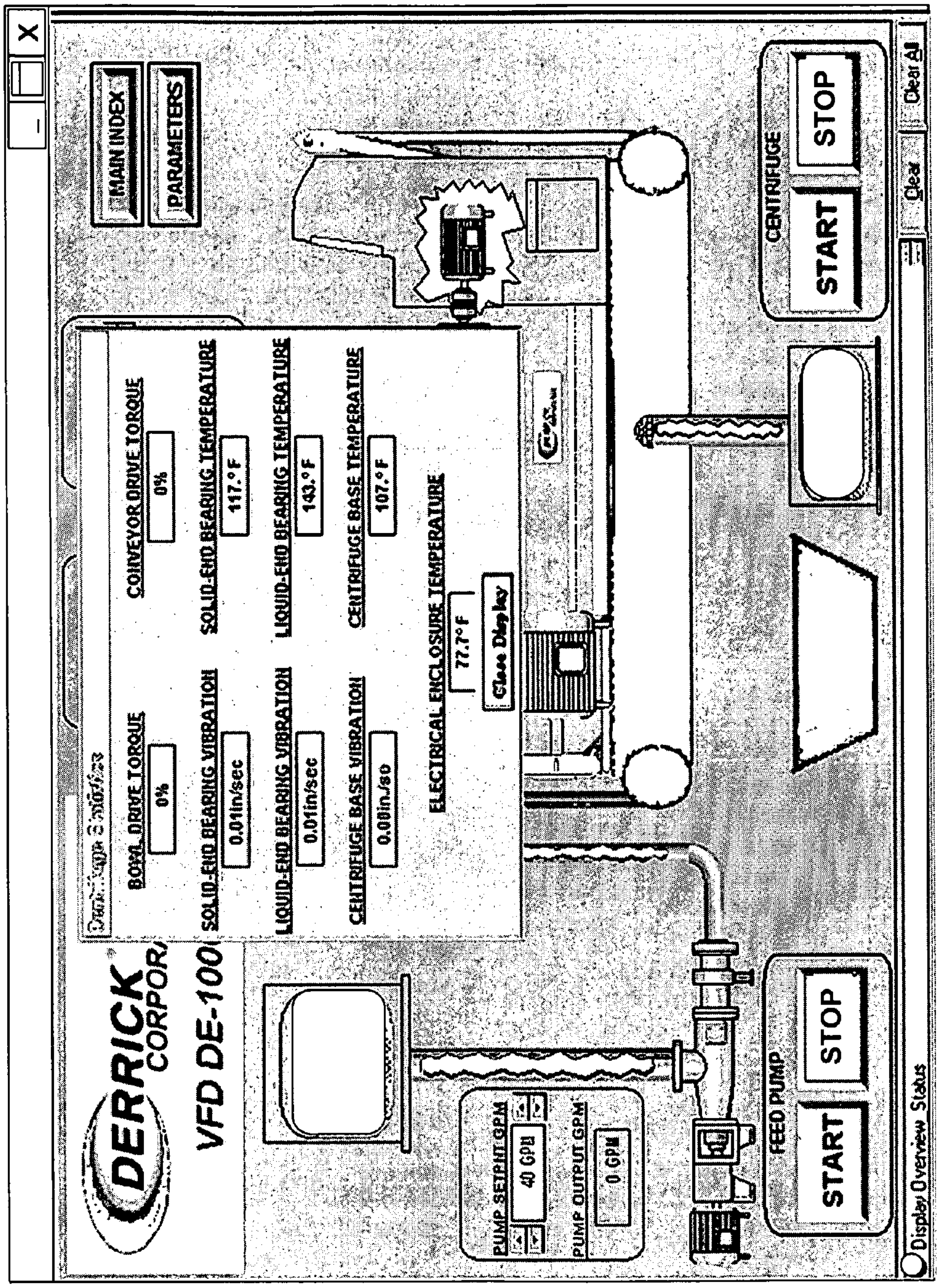

MAIN INDEX
PARAMETERS
DERRICK CORPOR
VFD DE-100
BOWL DRIVE TORQUE
0%
CONVEYOR DRIVE TORQUE
0%
SOLID-END BEARING VIBRATION
0.01in/sec
SOLID-END BEARING TEMPERATURE
117.°F
LIQUID-END BEARING VIBRATION
0.01in/sec
LIQUID-END BEARING TEMPERATURE
143.°F
CENTRIFUGE BASE VIBRATION
0.08in./se
CENTRIFUGE BASE TEMPERATURE
107.°F
ELECTRICAL ENCLOSURE TEMPERATURE
77.7°F
Close Display
PUMP SETPNT GPM
40 GPM
PUMP OUTPUT GPM
0 GPM
FEED PUMP
START
STOP
CENTRIFUGE
START
STOP
Display Overview Status
Clear
Clear All

Fig. 31

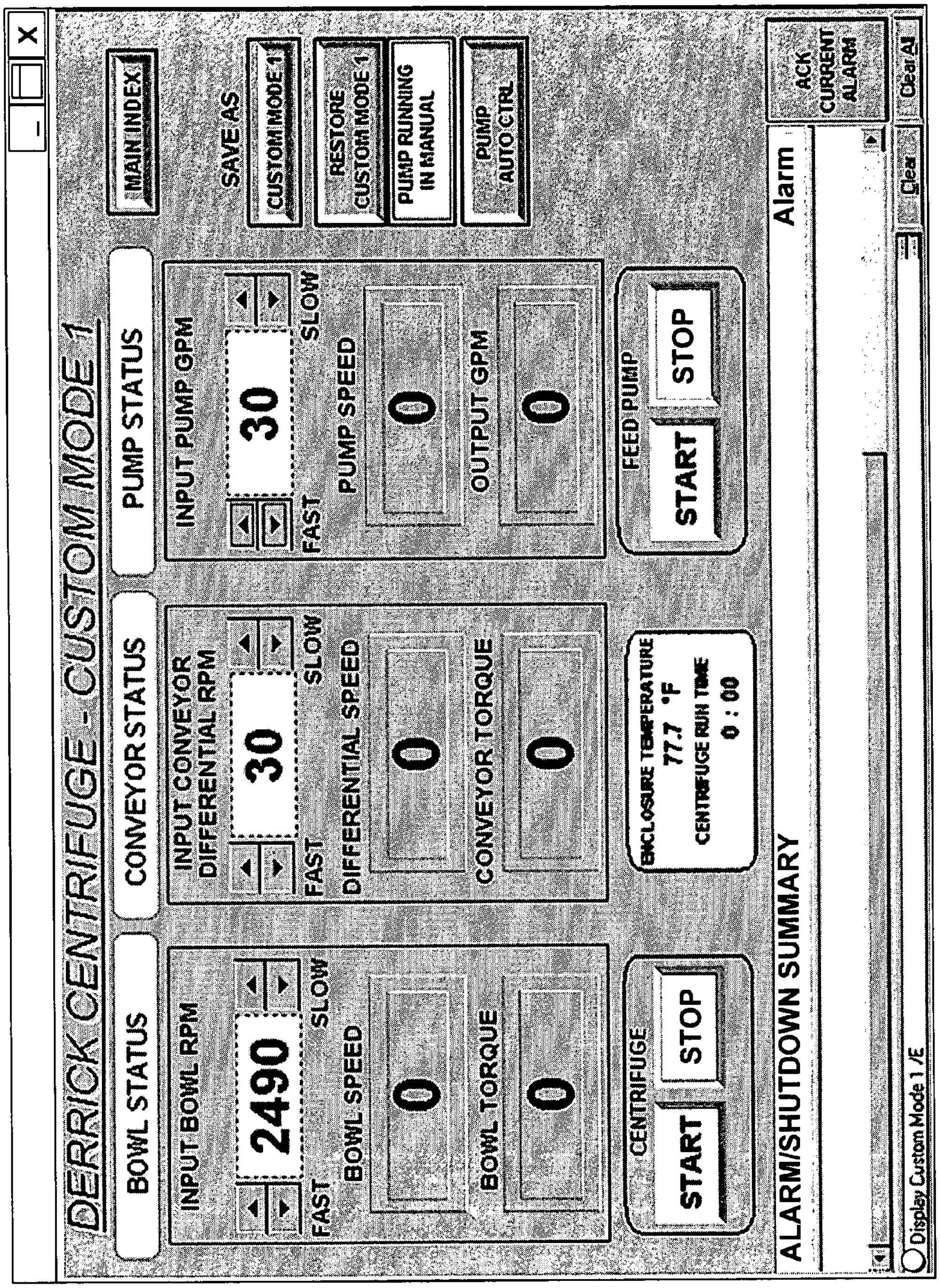

DERRICK CENTRIFUGE - CUSTOM MODE 1
MAIN INDEX
BOWL STATUS
CONVEYOR STATUS
PUMP STATUS
INPUT BOWL RPM
2490
FAST
SLOW
BOWL SPEED
0
BOWL TORQUE
0
CENTRIFUGE
START
STOP
INPUT CONVEYOR DIFFERENTIAL RPM
30
FAST
SLOW
DIFFERENTIAL SPEED
0
CONVEYOR TORQUE
0
ENCLOSURE TEMPERATURE
77.7 °F
CENTRIFUGE RUN TIME
0 : 00
INPUT PUMP GPM
30
FAST
SLOW
PUMP SPEED
0
OUTPUT GPM
0
FEED PUMP
START
STOP
SAVE AS
CUSTOM MODE 1
RESTORE CUSTOM MODE 1
PUMP RUNNING IN MANUAL
PUMP AUTO CTRL
ALARM/SHUTDOWN SUMMARY
Alarm
ACK CURRENT ALARM
Clear
Clear All
Display Custom Mode 1 /E

Fig. 32

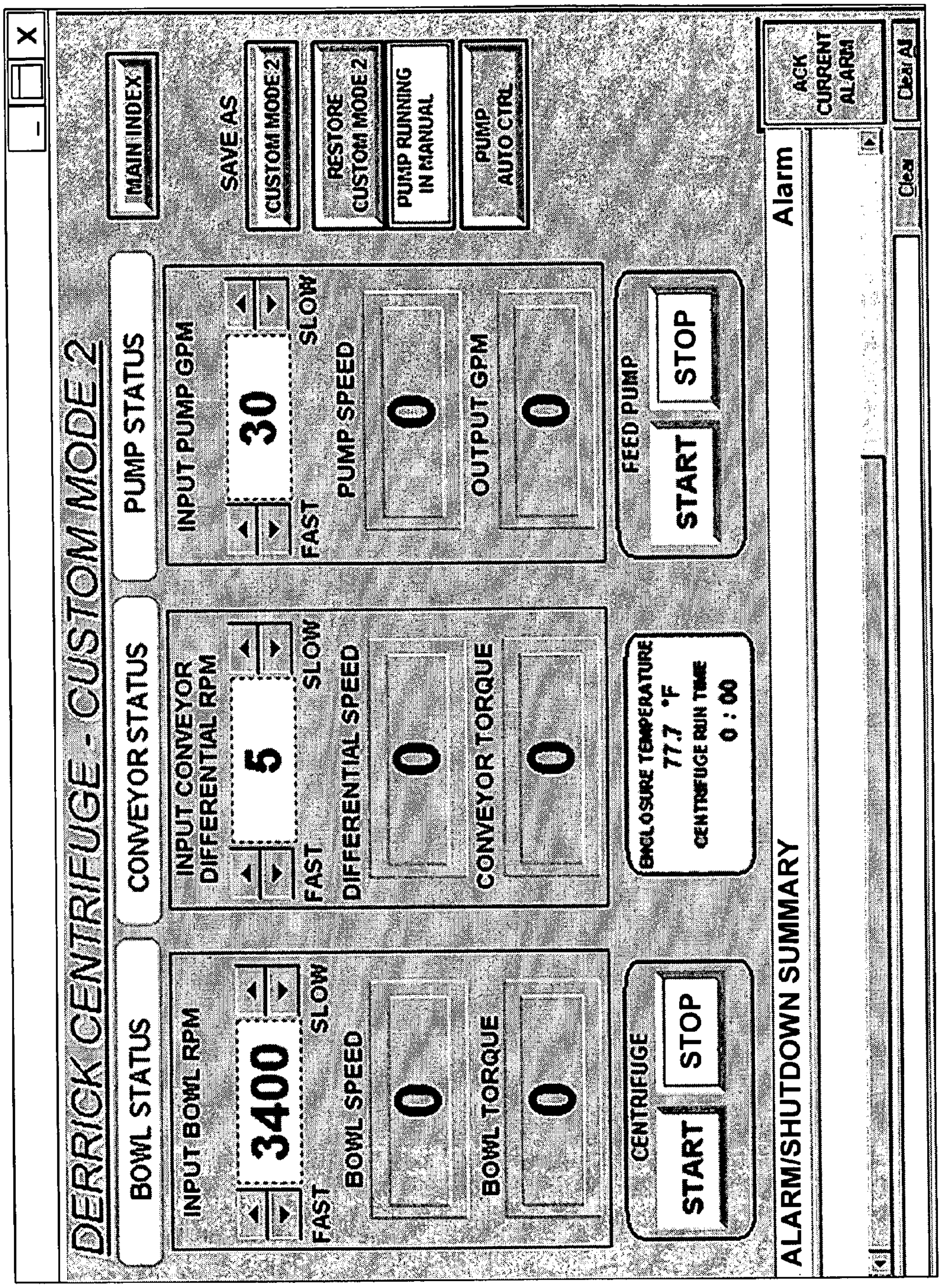

DERRICK CENTRIFUGE - CUSTOM MODE 2
MAIN INDEX
BOWL STATUS
CONVEYOR STATUS
PUMP STATUS
INPUT BOWL RPM
3400
FAST
SLOW
BOWL SPEED
0
BOWL TORQUE
0
INPUT CONVEYOR DIFFERENTIAL RPM
5
FAST
SLOW
DIFFERENTIAL SPEED
0
CONVEYOR TORQUE
0
INPUT PUMP GPM
30
FAST
SLOW
PUMP SPEED
0
OUTPUT GPM
0
SAVE AS
CUSTOM MODE 2
RESTORE CUSTOM MODE 2
PUMP RUNNING IN MANUAL
PUMP AUTO CTRL
CENTRIFUGE
START
STOP
ENCLOSURE TEMPERATURE
77.7 °F
CENTRIFUGE RUN TIME
0 : 00
FEED PUMP
START
STOP
ALARM/SHUTDOWN SUMMARY
Alarm
ACK CURRENT ALARM
Clear
Clear All

Fig. 33

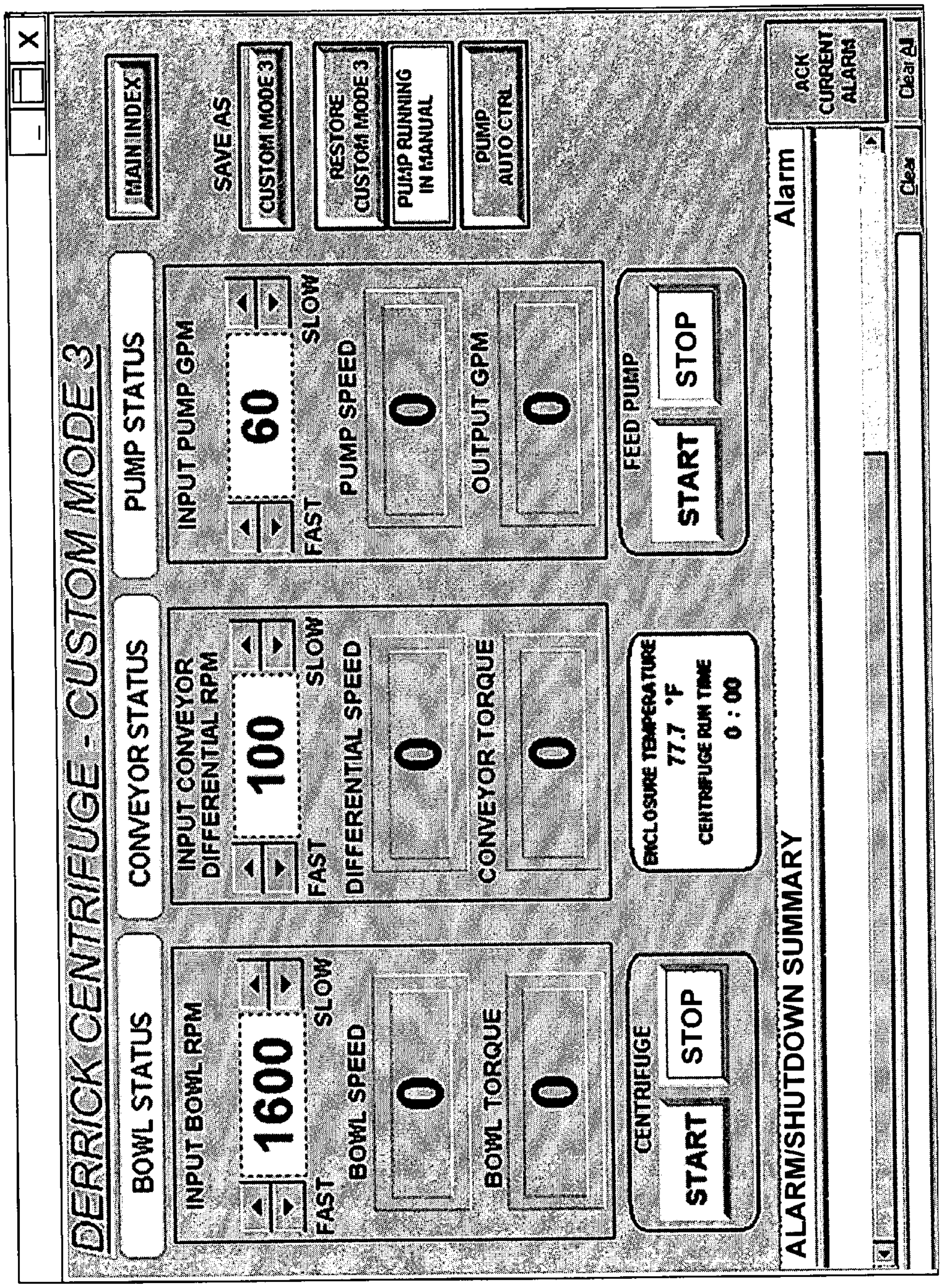

DERRICK CENTRIFUGE - CUSTOM MODE 3
MAIN INDEX
BOWL STATUS
INPUT BOWL RPM
1600
FAST
SLOW
BOWL SPEED
0
BOWL TORQUE
0
CENTRIFUGE
START
STOP
CONVEYOR STATUS
INPUT CONVEYOR DIFFERENTIAL RPM
100
FAST
SLOW
DIFFERENTIAL SPEED
0
CONVEYOR TORQUE
0
ENCLOSURE TEMPERATURE
77.7 °F
CENTRIFUGE RUN TIME
0 : 00
PUMP STATUS
INPUT PUMP GPM
60
FAST
SLOW
PUMP SPEED
0
OUTPUT GPM
0
FEED PUMP
START
STOP
SAVE AS
CUSTOM MODE 3
RESTORE CUSTOM MODE 3
PUMP RUNNING IN MANUAL
PUMP AUTO CTRL
ALARM/SHUTDOWN SUMMARY
Alarm
ACK CURRENT ALARM
Clear
Clear All

Fig. 34

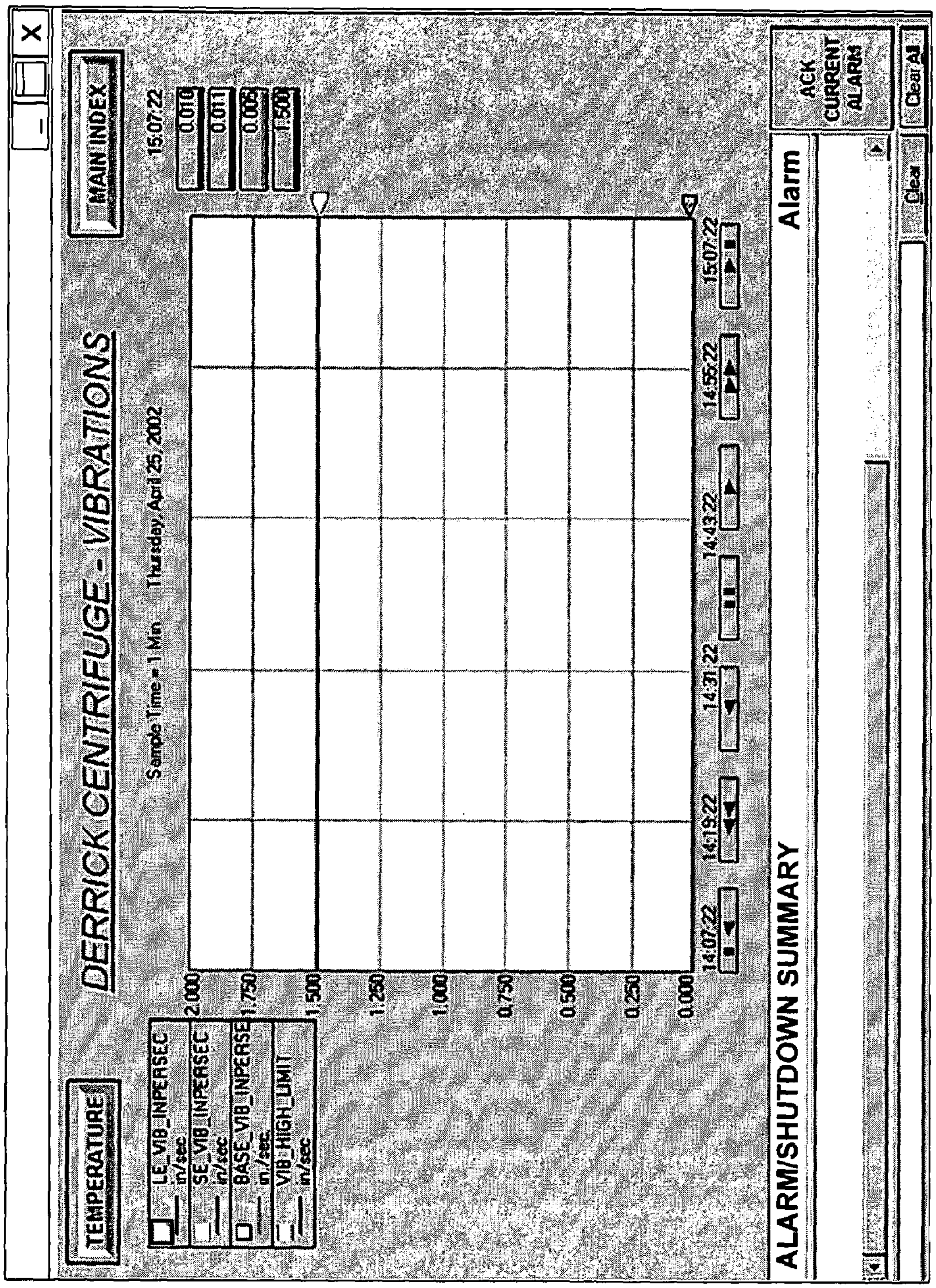

DERRICK CENTRIFUGE - VIBRATIONS
TEMPERATURE
MAIN INDEX
Sample Time = 1 Min
Thursday, April 25, 2002
LE_VIB_INPERSEC
in/sec
SE_VIB_INPERSEC
in/sec
BASE_VIB_INPERSE
in/sec
VIB_HIGH_LIMIT
in/sec
15:07:22
0.010
0.011
0.005
1.500
2.000
1.750
1.500
1.250
1.000
0.750
0.500
0.250
0.000
14:07:22
14:19:22
14:31:22
14:43:22
14:55:22
15:07:22
ALARM/SHUTDOWN SUMMARY
Alarm
ACK
CURRENT
ALARM
Clear
Clear All

Fig. 35

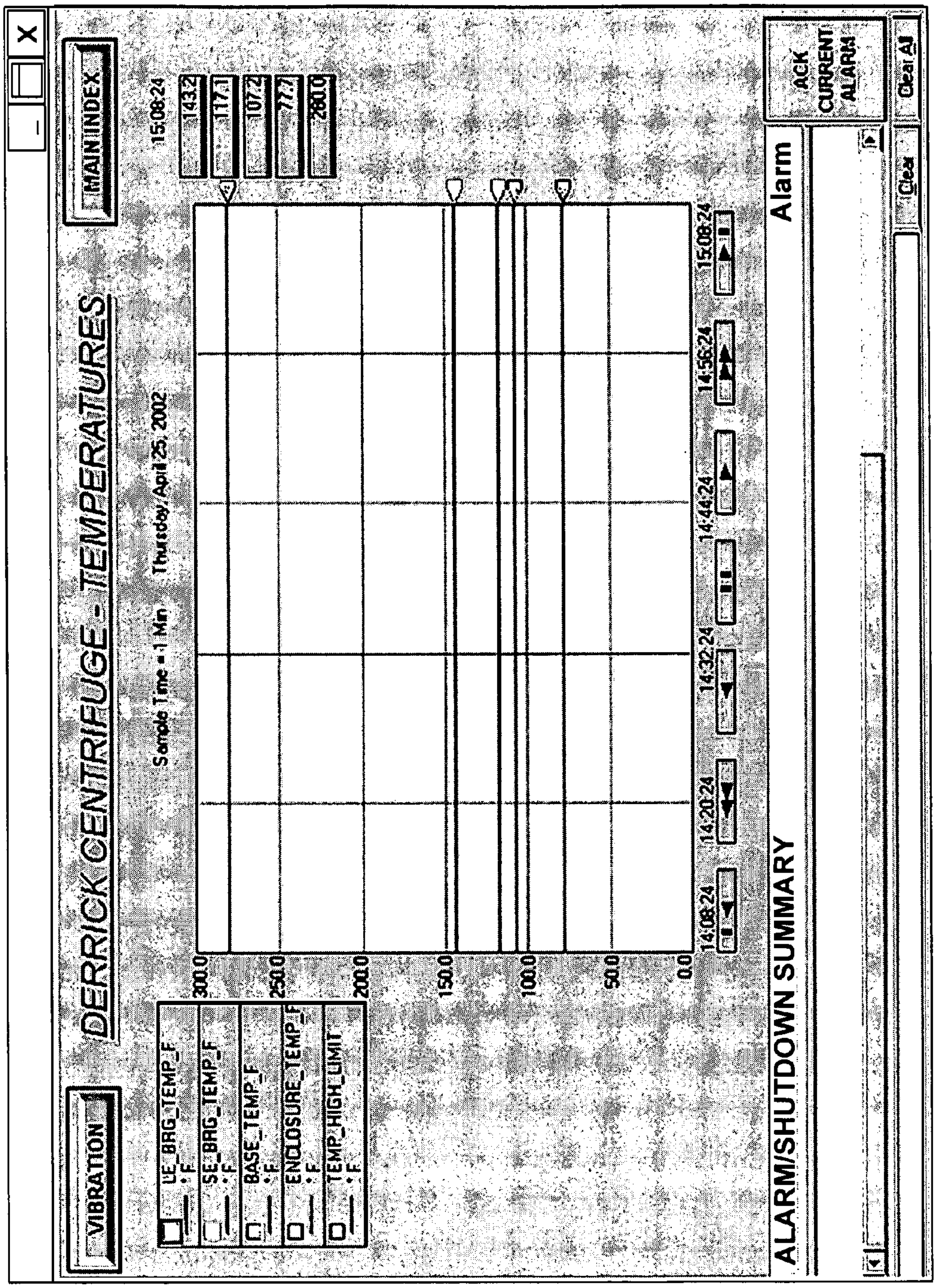

DERRICK CENTRIFUGE - TEMPERATURES
VIBRATION
MAIN INDEX
Sample Time = 1 Min
Thursday, April 25, 2002
15:08:24
LE_BRG_TEMP_F
°F
143.2
SE_BRG_TEMP_F
°F
117.1
BASE_TEMP_F
°F
107.2
ENCLOSURE_TEMP_F
°F
77.7
TEMP_HIGH_LIMIT
°F
280.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
14:08:24
14:20:24
14:32:24
14:44:24
14:56:24
15:08:24
ALARM/SHUTDOWN SUMMARY
Alarm
ACK CURRENT ALARM
Clear
Clear All

Fig. 36

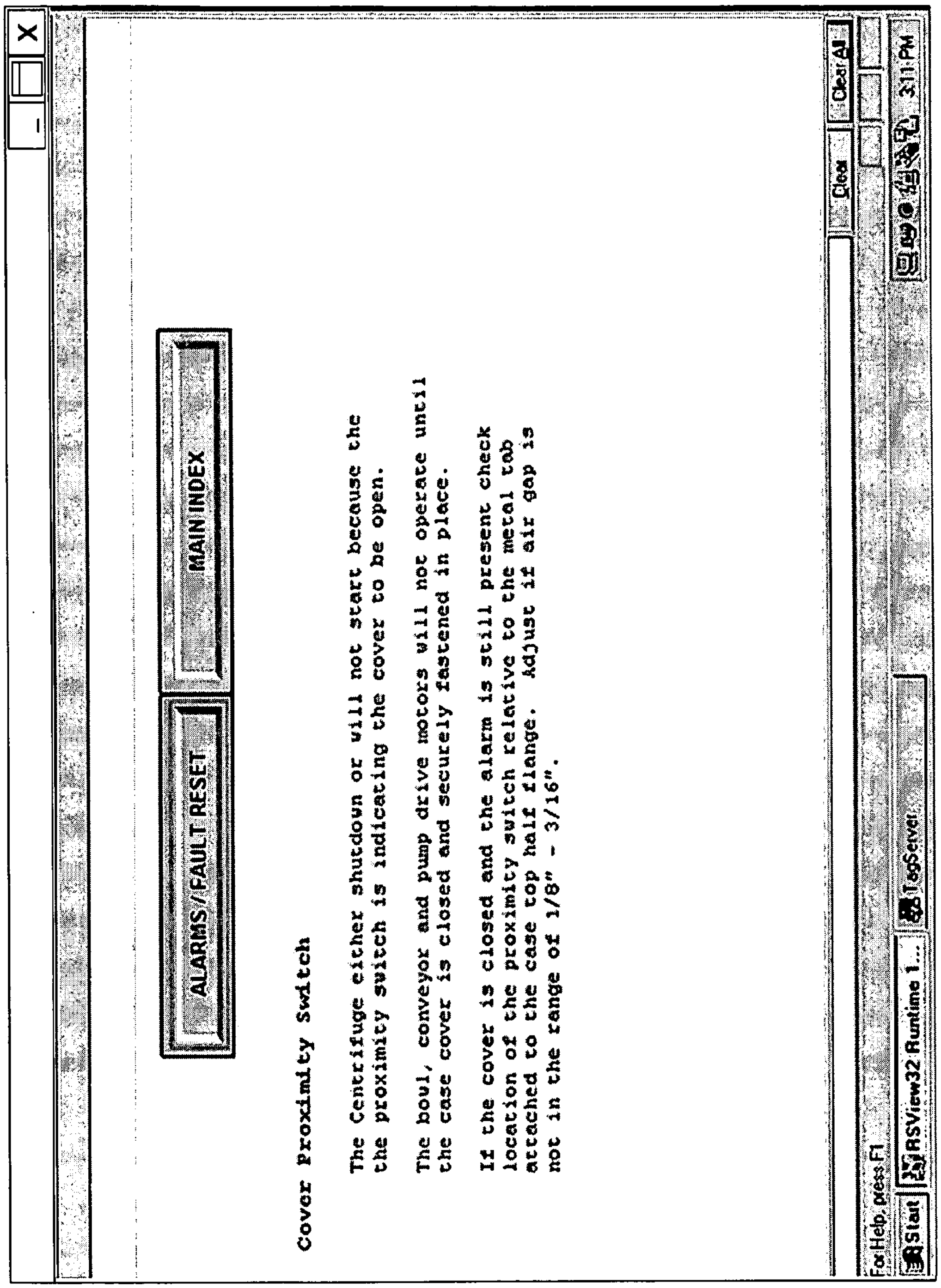

ALARMS/FAULT RESET
MAIN INDEX
Cover Proximity Switch
The Centrifuge either shutdown or will not start because the the proximity switch is indicating the cover to be open.
The bowl, conveyor and pump drive motors will not operate until the case cover is closed and securely fastened in place.
If the cover is closed and the alarm is still present check location of the proximity switch relative to the metal tab attached to the case top half flange. Adjust if air gap is not in the range of 1/8" - 3/16".
Clear
Clear All
For Help, press F1
Start
RSView32 Runtime 1...
TagServer
3:11 PM

Fig. 37

APPARATUS FOR CENTRIFUGING A SLURRY

RELATED APPLICATION

This is a continuation-in-part patent application under 35 USC 120 which claims the benefit of U.S. patent application Ser. No. 10/133,889, filed Apr. 26, 2002, entitled, "METHOD AND APPARATUS FOR CENTRIFUGING A SLURRY", and incorporated by reference herein.

REFERENCE TO COMPUTER PROGRAM LISTING APPENDIX

This patent includes a computer program listing appendix on compact disc. Two duplicate compact discs are provided herewith. Each compact disc contains a computer program listing as follows:

Filename: DERP101_US.txt Computer Program Listing
Size: 88 KB
Date Created: Apr. 26, 2002

The computer program listing appendix is hereby expressly incorporated by reference in the present application.

FIELD OF THE INVENTION

The present invention relates generally to a method and apparatus for centrifuging and, more particularly, to a method and apparatus for centrifuging which inherently and automatically safeguards against overloading the centrifuge, while maintaining efficient and effective centrifuging operation.

BACKGROUND OF THE INVENTION

One well-known type of centrifuge comprises a bowl and screw conveyor, each of which is driven by an electric motor. A danger in operating this type of centrifuge in some applications is that one or both of the motors may be presented with a load that will require the motor(s) to exceed rated torque. This could lead to motor failure and machine overload, in some circumstances, and to system shutdown. In some applications, such as oil well drilling, for example, down-time caused by centrifuge failure could be extremely expensive. One obvious solution to this problem known in the art is to simply monitor motor torque and shut down the entire system when overload occurs. Another known solution is to simply shut off the feed pump (which supplies a slurry to the centrifuge for separation) when overload occurs. Both of these known solutions are unsatisfactory, however, as they both adversely affect overall system performance and/or efficiency. In a solution to this problem in the parent patent of which this patent claims priority, predetermined limits were imposed on operating torque of both the conveyor and bowl motors. A drawback of this solution, however, is that the operator had no control over the predetermined torque limits and, under some operating conditions, the operator might want to run the motors within different limits. Another problem in existing centrifuge systems is that some users/operators have existing pump/gear box assemblies that they would like to use with a newly installed centrifuge. Heretofore, this was not possible, because the computer controlled centrifuges were not programmed to run with third party (i.e., other than OEM) pumps. What is needed, then, is a method and apparatus for centrifuging which continuously monitors motor torques,

permits operators to preset torque limits for conveyor and bowl motors, adjusts centrifuge operation automatically as load conditions change to ensure safe motor operation and efficient system operation, and can be used with customers' existing feed pumps.

SUMMARY OF THE INVENTION

The invention broadly comprises a method and apparatus for centrifuging. In one embodiment, the apparatus comprises a centrifuge for centrifuging a slurry, comprising a bowl driven by a bowl drive motor, a screw conveyor driven by a screw conveyor drive motor, a pump driven by a pump motor, a bowl drive unit operatively arranged to drive the bowl drive motor, a conveyor drive unit operatively arranged to drive the screw conveyor drive motor, a pump drive unit operatively arranged to drive the pump drive motor, and, a general purpose first computer specially programmed to control the bowl drive unit to drive the bowl drive motor at a first constant speed and to control the screw conveyor drive unit to drive the screw conveyor drive motor at a second constant speed and to monitor the torques of the bowl drive motor and the screw conveyor drive motor, while simultaneously controlling the pump drive unit to variably control flow of the slurry through the centrifuge so as to drive one of the bowl drive motor or the screw conveyor motor at a pre-set operating torque.

In a second embodiment, the centrifuge comprises a bowl driven by a bowl drive motor, a screw conveyor driven by a screw conveyor drive motor, a pump driven by a pump motor through a gear box having a gear box ratio and known pump output rate per revolution, a bowl drive unit operatively arranged to drive the bowl drive motor, a conveyor drive unit operatively arranged to drive the screw conveyor drive motor, a pump drive unit operatively arranged to drive the pump drive motor, and, a general purpose first computer specially programmed to control the pump drive unit to variably control flow of the slurry through the centrifuge in accordance with the gear box ratio and known pump output rate per revolution until such time as the load of the slurry causes one of the bowl drive motor or the screw conveyor motor to exceed an operator set operating torque for the bowl drive motor or the screw conveyor motor, respectively.

In a system having a centrifuge comprising a bowl and screw conveyor driven by a bowl motor and screw conveyor motor, respectively, the system also having a feed pump driven by a pump motor to provide a slurry load to be centrifuged by the centrifuge, the invention also comprises the method of controlling the system, comprising the steps of:

a. manually setting an operating torque set-point for the screw conveyor motor and the bowl motor; and,
b. automatically controlling the pump motor to regulate the feed pump until the slurry load demands more than the manually set operating torque for the screw conveyor motor or the bowl motor.

In a system having a centrifuge comprising a bowl and screw conveyor driven by a bowl motor and screw conveyor motor, respectively, the system also having a feed pump driven by a pump motor through a pump gearbox having a gearbox ratio to provide a slurry load to be centrifuged by the centrifuge, the invention broadly comprises the improved method of controlling the system, comprising the steps of:

a. manually setting a feed pump gear box ratio and feed pump output rate per revolution for the feed pump;

b. manually setting an operating torque set-point for the screw conveyor motor and the bowl motor; and,

c. automatically controlling the pump motor to regulate the feed pump until the slurry load demands more than the manually set operating torque for the screw conveyor motor or the bowl motor.

A general object of the invention is to provide a method and apparatus for centrifuging which protects against centrifuge shutdown due to overloading of centrifuge motors.

A secondary object of the invention is to provide a method and apparatus for centrifuging which protects against overload of centrifuge motors by regulating the pump motor which, in turn, regulates the pump feeding slurry to the centrifuge, in response to monitored conditions of torque developed by centrifuge screw conveyor and bowl motors.

A further object of the invention is to provide a method and apparatus for centrifuging which permits an operator of the system to preset maximum torque operating levels for the screw conveyor and bowl motors, regulates the centrifuge feed pump while monitoring the torques developed by both conveyor and bowl motors, and takes appropriate action when preset torque limits are exceeded by either the conveyor or bowl motor (such as shutting down the pump drive motor, shutting down the conveyor and bowl motors, or, ultimately shutting down the centrifuge system.)

Another object of the invention is to provide a centrifuge system that is configured to use a customer's or operator's existing feed pump, by permitting certain specifications of the feed pump to be entered into the control computer of the centrifuge system, thereby avoiding the need for the customer to purchase an integral pump with the system.

These and other objects, features and advantages of the present invention will become readily apparent to those having ordinary skill in the art from a reading and study of the following detailed description of the invention, in view of the drawing and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of a centrifuge system wherein a centrifuge receives a slurry for separation and includes drives, motors, pumps and computer controls coupled thereto;

FIGS. **2–7** are flow charts depicting the logic for implementing the control of the variable frequency drive centrifuge;

FIGS. **8–12** are flow charts illustrating the logic for the data conversion and averaging subroutine;

FIGS. **13–17** are flow charts illustrating the logic of the alarm and shutdown subroutine; and,

FIGS. **18–37** represent screen captures illustrating the user interface with the computer control system of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

It should be appreciated at the outset that the method and apparatus of centrifuging of the invention is suitable for use in a variety of applications—virtually any application that requires a centrifuge. In a preferred embodiment of the invention, the patentee tested the invention in an earth drilling application. Thus, while the description herein describes the invention in this particular application, it should be appreciated that the appended claims are not intended to be so limited. In addition, it should be appreciated that the centrifuge of the present invention is adaptable for use in either closed or open systems.

In reading this patent, it should be appreciated that like reference numbers on different drawing views represent identical structural elements of the invention. It should also be appreciated that the centrifuge of the present invention is ultimately controlled by a general purpose industrial hardened computer specially programmed to control the bowl drive motor, the screw conveyor motor, and the pump motor. The computer also provides a user interface in the form of a monitor and is controlled through an attached pointing device (mouse). The source code running on the processor of the invention is included in the compact disc appendix, and is incorporated herein by reference.

Adverting now to FIG. **1**, centrifuge **10** of the inventive system includes a bowl **11** and a screw conveyor **12**, the specific structure of which is well known in the art. The centrifuge **10** receives a slurry via conduit **45** into pump **15** which then pumps the slurry to the centrifuge via conduit **17**. The bowl **11** is driven by bowl motor **19** via pulley arrangement **20**, and screw conveyor **12** is driven by conveyor motor **21** via gear box **23**. The high density solids, which are separated from the slurry, are discharged from centrifuge **10** through conduit **24**. The remaining portions of the slurry (effluent) are ejected from the centrifuge via conduit **25**. The bowl **11** is supported by two bearings **27** and **29**. Conveyor motor speed and direction information is detected by encoder **46** and communicated to conveyor drive unit **31** via line **42**.

The above described centrifuge system is computer operated. In this respect, in accordance with a computer program which is included in the compact disc appendix, and incorporated by reference herein, a local general purpose industrial hardened computer **30** monitors the torque of the conveyor motor **21** and bowl drive motor **19**. Speed and directional information about the conveyor motor is sensed by encoder **46**, and transmitted to conveyor drive **31** as well. First computer **30** also communicates with pump drive **34**, operatively arranged to drive pump motor **35** which in turn drives pump **15**. A remote (second) general purpose computer **37** is linked to the local computer **30** via line **39** so that troubleshooting or operation of the system can be monitored and controlled from a remote location, if desired. In a preferred embodiment, the two computers are linked by a telephone modem using commercially available PC Anywhere® software, available from Symantec Corporation, 20330 Stevens Creek Blvd., Cupertino, Calif. It should be appreciated, however, that the two computers can be linked over a network (e.g., LAN), or over a global information network such as the Internet (later versions of PC Anywhere are capable of linking computers over the Internet). Also coupled to computer **30** are transducers associated with bearings **27** and **29** via lines **40** and **41**, respectively, to thereby monitor the conditions (vibration and temperature) reflected at these bearings, as is also discussed in detail hereafter in relation to the flow charts and the descriptions of the various programs.

Broadly, in accordance with the present invention the mode of operation of the above-described system produces efficient centrifuge operation with concurrent safe operation of the motors that run the centrifuge. Also, in some modes of operation, throughput of the slurry passing through the centrifuge is maximized while maintaining consistency of separation.

The present invention comprises three general levels of security with respect to operation. First, under some user-selected preprogrammed modes, the system automatically adjusts pump speed and flow while preventing the conveyor and bowl motors from operating in an overload condition, that is, above rated torque. Importantly, this is accomplished while holding bowl speed constant and screw conveyor speed constant (and therefor holding their respective motor speeds constant). Second, in the event rated torque is developed by either of the motors, the system in some modes will shut down the pump. Third, in the event either of the centrifuge motors begins to operate at a dangerous level above rated torque, the system in some modes will shut down the entire system, that is, the pump and the centrifuge will shut down. The torque limit for pump shutdown (level 2) and system shutdown (level 3) are predetermined and programmed into the computer of the invention.

With respect to the first level of protection, in this mode, the speed of rotation of the bowl **11** and the speed of rotation of the screw conveyor **12** are preset by the operator at specific values and maintained constant for each specific type of slurry. In this respect, the operator has knowledge of the characteristics of the specific slurry (e.g., drilling mud and trailings) which is received from the well, and he selects the bowl and screw conveyor speeds for this specific slurry for best separation of the trailings (solids). The torque of the conveyor motor and the torque of the bowl motor which are developed at the specific speeds are measured and monitored. Both of these torques are represented and displayed as a percent of rated torque of their respective motors. The torque associated with the motor operating at the highest percentage of rated torque is designated the predominant torque, and it is this torque which is fed into a PID feedback loop to control pump speed and flow. (Each motor has an associated PID feedback loop associated with it.) If the predominant torque varies from the desired percent of rated torque the computer causes the pump motor to vary the flow to the centrifuge **10** to thereby maintain the desired percent of rated torque while maintaining the speed of the bowl and the speed of the screw conveyor constant, albeit at different speeds. By virtue of the foregoing mode of operation the trailings are removed from the slurry in an efficient manner. In this respect, specific types and quantities of trailings are removed without removing more than those specific trailings or less than those specific trailings. In other words, if the speed of the bowl motor was increased, drilling mud of less weight than the specific trailings would be removed from the slurry and discarded with the trailings. If the speed of the bowl was decreased, undesirable trailings would be retained in the slurry and conducted back to the tank, thereby lessening the efficiency of the separation. If the speed of the screw conveyor was increased, more than the specific trailings could be discharged and discarded, thereby possibly losing expensive drilling mud. If the speed of the screw conveyor motor was decreased, excess accumulations of trailings could be experienced on the inside of the bowl, which could results in loading the conveyor motor excessively. Most importantly, the system of the invention prevents either of the motors from overloading while simultaneously operating them at constant speeds, compensating for variable demands of load torque by varying pump flow and speed.

In a preferred embodiment disclosed herein, the operator can preset an upper operating torque limit for the screw conveyor and bowl motors. In operation, the feed pump motor is controlled by the above-mentioned PID feedback loop until such time as the operating torque developed by either the screw conveyor motor or bowl motor exceeds the operator determined preset limit for either motor, at which time the computer control stops operation of the feed pump. At higher levels of developed operating torque (preprogrammed), the bowl and conveyor motors are shut down, and, at even higher predetermined levels, the entire centrifuge system is shut down.

With respect to the oil drilling application of the present invention, reference has been made above to drilling mud and trailings. The drilling mud may be any composition well known in the art which is used in well-drilling operations in the search for oil, and it is used in the conventional manner. The trailings are the substances which are removed from the earth as a result of the drilling operation and are brought to the surface with the drilling mud.

The Software of the Invention

In addition to PC Anywhere described above, there are two general software aspects of the invention. The first software application is written in Rockwell Software's RSLogix™ 5, commercially available from Rockwell Automation, 1201 South Second Street, Milwaukee, Wis. RSLogix software is used to program the PLC-5 family of programmable logic controllers and Softlogix controllers, which, as is well known, are used to control a wide variety of industrial equipment. In the present invention, the PCs control the variable frequency motor drives for both the screw conveyor and bowl motors, as well as the drive for the pump motor.

The second software application is written in RSView™, also available from Rockwell Automation. This software is used to generate the user interface screens shown in FIGS. **18–29**.

Source code listings for both of the above-mentioned software applications are included in the attached compact disc appendix, and incorporated herein by reference. It should be apparent to those having ordinary skill in the art that other software applications in other programming languages could accomplish the same result in substantially the same way as the software of the present invention, and these alternatives are intended to be within the spirit and scope of the invention as claimed.

Operation and Use of the Invention

At the outset, it should be appreciated that, while in a preferred embodiment, the screw conveyor motor is a 10 horsepower motor connected to the conveyor through a gearbox, and the bowl motor is a 50 horsepower motor, both of which are driven by variable frequency drives, that other horsepower combinations could be used, depending upon the loads expected. Automatic load sensing and feed pump control enable automated performance optimization. In a preferred embodiment, the bowl assembly can be operated in a range between 1 to 4000 RPM, which can result in an internal centrifugal acceleration of more than 3000 G's, although clearly the invention as claimed is not limited in scope to any particular horsepower and/or speed range. Similarly, to accommodate low levels of agitation and rapid solids removal, in a preferred embodiment, the conveyor is capable of differential speeds in the range of 1 to 100 RPM, although this range is not critical to the invention as claimed.

Each motor is powered by a high performance PWM (pulse width modulated) AC drive with IGBT (insulated gate bipolar transistor) outputs. In turn, each of the motor drives and other peripheral devices are controlled by an environmentally hardened IBM compatible personal computer. The PC and all devices communicate through a high-speed, machine level control network (e.g., DeviceNet).

This PC control enables long-term data storage so that historical data can be logged into historical trends. In addition, with a remote PC, remote monitoring and control of the centrifuge can be accomplished from an adjacent room or from thousands of miles away. Various configurations are possible, regarding security and read/write capability, and a simple telephone line connection to the onboard high-speed modem or Ethernet connection to a Local Area Network (LAN) can provide multiple users "real-time" machine status information. Remote connection capability can also be made over the Internet, and is a powerful tool for troubleshooting and correcting suspected malfunctions without going on-site.

The centrifuge of the present invention can be operated in either a manual or automatic mode. In a manual mode, the operator sets bowl motor speed and conveyor motor speed (by setting the differential speed) and also sets the input pump GPM. The computer monitors torque developed by the screw conveyor motor and bowl motor. If developed torques exceed a first preset limit, the pump motor shuts down. If developed torques exceed a second preset limit, the conveyor and bowl motors shut down. In the automatic mode, the computer takes over control of the pump motor to ensure that the torque developed by the conveyor and/or bowl motors do not exceed predetermined limits. If the developed torques approach these predetermined limits, the computer "backs off" on the pump, by decreasing speed and/or flow to reduce the load presented to the centrifuge motors. In a preferred embodiment and operating mode described in this patent, the operator can preset a desired operating torque (as a percentage of rated torque) for the bowl and conveyor motor (the preset torque value is a target for either the bowl or conveyor motor, whichever develops this percentage of rated torque first controls.) In this auto control mode, the computer controls the pump to achieve the desired operating torque level. As in the previously described modes, however, if the load causes an overload condition for either the bowl or conveyor motor, the computer is programmed to first shut down the pump drive motor, and, at a higher torque overload condition, to shut down the centrifuge motors (conveyor and bowl motors). Thus, the present invention enables multiple modes of operation, some being predefined and some being user configurable. Predefined modes consist of typical settings for Solids Removal and Barite Recovery. If these predefined settings are not sufficient or optimum, custom setups can be saved by the operator and recalled by clicking a single button. Additionally, feed pump control can be automatic or manual. Automatic control, primarily designed for Barite Recovery, maximizes centrifuge throughput by employing a PID proportional-integral-derivative) loop. This increases pump output to the centrifuge until the operator input torque set point is reached on either the bowl or conveyor drive motors. If properties of the feed slurry change, the PID loop will dynamically adjust pump output to maintain the torque set point (the operator actually sets motor speed, and thereby impliedly sets the torque set points). This enables even less experienced operators to safely and effectively operate and monitor the apparatus.

The PC also continuously runs a diagnostic program which provides the operator with machine critical status information. Real-time trends of main bearing temperature and vibration levels as well as base vibration and enclosure temperature can be viewed on demand. Messages inform the operator when minimum and maximum bowl, conveyor and pump speeds have been reached. In the event alarms or faults do occur, detailed descriptions pinpoint the cause of the malfunction and enable rapid recovery.

Operation of the invention is best understood with reference to the screen captures of FIGS. **18–37**. These screen captures illustrate the user interface of the invention. In operation, the operator operates much of the system from a control panel including a monitor and pointing device, such as a mouse. In a preferred embodiment, the system is so easy to use that a keyboard interface is not required. It should be appreciated, however, that other means of communicating with the computer could be used, such as keyboards, voice recognition, and touch-screens, to name but a few.

The main system screen is shown in FIG. **18**. From this screen the operator has a variety of options and modes of operation, as shown. The operator can select Manual Operation, Solids Removal mode of operation, Barite Recovery mode of operation, Alarms, Data/Setup, one of three different Custom Modes (Custom Mode 1, Custom Mode 2, Custom Mode 3), Vibration Trends, Temperature Trends, or Visual Operation, each of which is described seriatim herebelow.

If the operator clicks the MANUAL OPERATION button in the screen shown in FIG. **18**, the screen shown in FIG. **19** appears. The screen of FIG. **19** allows an operator to monitor and/or set Bowl Speed, Differential Speed (and therefore Conveyor Speed) and Feed Pump GPM. On this screen, the operator selects and sets (by mouse interaction with the up/down (▲/▼) icons on the screen) desired Input Bowl RPM and Input Conveyor Differential RPM which indirectly sets the screw conveyor speed (the conveyor differential RPM is the difference between the bowl RPM and the screw conveyor RPM). In the example shown, the operator has set the bowl speed at 3000 RPM, and the conveyor differential speed at 50 RPM. In the MANUAL OPERATION mode, the operator can also set the pump flow rate (as shown under the Pump Status column) and, in the example shown in FIG. **19**, the operator has set the pump to a flow rate of 30 GPM. Once the desired parameters are set (as indicated as "black on white" numbers in the fields adjacent the up/down icons), the operator can start the centrifuge by clicking on the START button under the word CENTRIFUGE, and can start the feed pump by clicking on the START button under the words FEED PUMP. Once the centrifuge and pump have been started (FIG. **19** shows the centrifuge in STOP mode), the actual measured bowl speed (0 RPM), bowl motor developed torque as a percentage of rated torque (0%), differential speed (0 RPM), screw conveyor motor developed torque as a percentage of rated torque (0%), pump speed, and pump output GPM are displayed. (In FIG. **19**, the bowl speed and torque, differential speed and torque, pump speed and pump output GPM are all zero because the operator has not yet started the feed pump). In FIG. **19**, these measured parameters are shown as "black on gray" in fields under their respective headings, under the general headings "Bowl Status", "Conveyor Status", and "Pump Status", respectively. This screen also displays enclosure temperature and centrifuge run time. The preset settings from this screen can be saved as Custom Modes for future use by clicking on the appropriate Custom Mode button (1, 2 or 3) under the SAVE AS wording on the upper right of the screen. This screen also provides the operator with an Alarm/Shutdown Summary in the window at the bottom of the screen, where he can view or acknowledge the most recent alarm. Examples of alarm conditions include a centrifuge motor exceeding rated torque, excessive bearing temperature or vibration, excessive enclosure temperature, and a number of other conditions. Finally, this screen includes icons for selecting manual or automatic pump running modes (in FIG. **19**, pump running mode is selected as manual as evidenced by the "black on gray" status of this icon). The operator would select automatic operation by clicking on the Pump Auto Ctrl button. As described previously, in the automatic mode, the computer would automatically control the pump to meet preselected or predetermined torque operating conditions.

Selection of the SOLIDS REMOVAL button on the screen shown in FIG. **18** launches the screen shown in FIG. **20**. This mode includes preset (at the factory) settings for desired bowl speed (e.g., 3000 RPM) and conveyor differential speed (70 RPM) to achieve a desired consistency of separation of the slurry. As the slurry is presented to the motors as a load, each motor (bowl and conveyor) develops the necessary torque to meet the demands of the load at the preset speeds. The operator can change the preset speeds during operation. In FIG. **20**, the operator has started the centrifuge, as indicated by the display of bowl RPM and conveyor differential RPM, but has not yet activated the feed pump (by clicking on the START button under the words FEED PUMP). Once he starts the feed pump, the computer will automatically display the speed and flow of the pump. In this and other manual and automatic modes of operation in a preferred embodiment, the computer is programmed to monitor torques developed by the conveyor and bowl motors and continuously (at a sampling rate of approximately 50 ms) compare the developed torque to rated torque. If the developed torque of either motor reaches a first preset level (above rated torque), the computer will shut down the pump. If the developed torque of either motor reaches a second preset level above the first preset level, the computer will shut down the centrifuge (by shutting down the conveyor and bowl motors). Again, in the BARITE RECOVERY mode, the operator has an option to run the system manually or automatically. As can be seen by the "black on gray" status of the PUMP RUNNING IN MANUAL button, the Barite Recovery mode of FIG. **21** is set for manual. However, it should be appreciated that the Barite Recovery mode may be set for the automatic, as indicated by the PUMP AUTO CTRL button shown on the screen. In the automatic mode, the pump speed and flow rate are automatically controlled in response to measured torque from the screw conveyor and bowl motors. It should also be appreciated that, although the auto control mode is described herebelow with respect to a barite recovery program in an oil drilling application, this mode of operation obviously has many other applications.

By way of introduction to the oil drilling application, barite, or heavy spar, is a sulfate of barium, $BaSO_4$, found in nature as tabular crystals or in granular or massive form and has a high specific gravity. Most crude barite requires some upgrading to minimum purity or density. Most barite is ground to a small, uniform size before it is used as a weighting agent in petroleum well drilling mud specification barite. Barite is relatively expensive, and an important objective of a preferred embodiment of the present invention is to recover barite from the slurry in an oil drilling operation for re-use. In the mode shown in FIG. **21**, then, the operator has set the bowl speed to 1800 RPM, and the conveyor differential speed to 90 RPM. He has also set the pump GPM to 40. The system, through the aforementioned PID loop and computer control, is adjusting the pump speed (approximately every 50 ms), to achieve the desired pump GPM. In this screen capture, the operator is running the system in the manual mode.

Should the operator select automatic mode (by clicking on the Pump Auto Ctrl button), the system, through a PID feedback loop linked to the motor operating closest to its rated torque (defined as the predominant torque) would control the pump speed and flow. The idea is to control the pump to optimize operation while simultaneously protecting against either conveyor or bowl motors exceeding their rated torque limits. Both the speed and flow of the pump will vary during operation as the system in this mode operates to maintain constant bowl speed (a first speed) and constant conveyor speed (a second speed). In operation, the computer senses and measures the torque developed by the screw conveyor motor and bowl motor. The measured torques are compared against the rated torques of the respective motors and then represented as a percentage of rated torque. Whichever motor is operating at a higher percentage of rated torque is defined as the predominant torque motor. It is this motor's (predominant) torque which controls a PID loop to control pump flow and speed. It is possible during operation that one motor predominates, and, at a later point in the same operation, that another motor predominates. Each motor has its own PID control loop, each of which is operatively arranged to control pump speed and flow when called upon to do so by the computer.

As described previously, the system is preprogrammed to monitor various alarm conditions. For example, FIG. **22** illustrates ALARM HISTORY screen, launched by clicking the ALARMS icon of the screen of FIG. **19**. The Alarm History screen provides the announcement of a specific alarm condition, for instance, Maximum Differential Speed Limit Reached is one type of alarm condition that can be displayed. It is also possible to view a log of historical alarm notices, by clicking on the VIEW ALARM LOG FILE button in the lower center section of the screen shown in FIG. **22**. Once this button is clicked, an alarm log is launched to display the detailed history of past alarm conditions. The log may include such detailed information as the date and time of the alarm, and a detailed description of the alarm itself.

From the main screen shown in FIG. **18**, the operator can also access the Data/Setup button, which launches a set of options shown in the screen capture of FIG. **23**. Some of these options (System Login) are not particularly germane to the invention. The ALARMS/FAULT reset button is used to reset alarms. The MAIN INDEX button is used to return to the screen shown in FIG. **18**. The HISTORICAL DATA button is used to view various historical data, such as that shown in FIG. **24** for bearing temperature and vibration and enclosure temperature. The SYSTEM DATA icon is used to view information pertaining to the operation of the centrifuge and its associated systems as shown in the screen of FIG. **25**. As can be seen, the SYSTEM DATA screen allows an operator to obtain and view various operating parameters, such as bowl drive actual speed, conveyor drive actual speed, pump drive actual speed, bowl drive actual torque, conveyor drive actual torque, pump drive actual drive, bearing vibrations and run times. Clicking on either the Data/Setup button or the Main Index button returns the user to the screens shown in FIGS. **23** and **18**, respectively.

From the screen shown in FIG. **23**, by pressing the Centrifuge Status button, an operator can also launch the CENTRIFUGE STATUS screen of FIG. **26**, which provides information concerning the operational status of the centrifuge and whether the centrifuge is operating within parameters. As shown in FIG. **26**, the CENTRIFUGE STATUS screen provides information concerning bowl and conveyor drives and torque, power supply, motor thermal overloads, the feed pump drive, vibration levels, bearing temperatures, enclosure temperature and whether the case cover is closed.

By clicking the Auto Control Setup button of the screen in FIG. **23**, the AUTO CONTROL SETUP window of FIG. **27** is opened, which allows an operator to set the centrifuge to automatically operate according to operator defined parameters based on bowl and conveyor drive motor developed torques. As shown in FIG. **27**, the operator has preset the desired torque operating level to 75%, but this level can be modified by clicking the up/down (▲/▼) icons. Once the torque level is set, the centrifuge will automatically regulate feed pump output until the developed torque by the conveyor motor OR the conveyor motor reaches the set-point (whichever motor reaches this level first). The computer will maintain this operating condition. It should be appreciated that, in this mode, both the conveyor motor and bowl motors are operating at constant, albeit possible/probably different speeds, while the pump motor speed and flow are regulated. It should also be appreciated that, even in this mode, it is possible that the feed will cause a motor overload, and that at a first overload condition (as determined by developed motor torque) the system will shut down the pump, and at a second higher torque overload condition, the conveyor and bowl motors will shut down. It should be appreciated that these alarm conditions can be determined by measuring developed torque or operating current.

As described previously, one embodiment of the present invention enables operators to use pre-existing feed pumps with the computer controlled centrifuge of the present invention. To do this, the system needs to know certain parameters about the existing feed pump. To launch the feed pump configuration, an operator clicks the Feed Pump Setup button on the screen of FIG. **23** to launch the PUMP CONFIGURATION screen of FIG. **28**. As shown in FIG. **28**, the operator enters the feed pump gearbox ratio and feed pump output rate (Gal./Rev.), by clicking the appropriate up/down (▲/▼) icons. In the instant case, the feed pump gearbox ratio is set at 10.20:1 and the feed pump output rate is 0.80 Gal./Rev. This embodiment permits a customer of the centrifuge to use an existing positive displacement pump, or positive displacement pump from a manufacturer of his choice rather than ordering the centrifuge system with integral pump. Once the parameters described above are entered, the computer, by transmitting speed reference commands to the variable frequency drive (VFD), and reading actual motor speed back from the VFD, is capable of calculating actual pump flow rates. It accomplishes this by looking at the actual motor speed, at that instant in time, and using the pump gearbox ratio to calculate the speed of the pump rotor. Knowing the speed of the rotor and the fact that its a positive displacement pump and knowing the rated output per revolution, a simple mathematical relationship is used to calculate flow rate in gallons per minute.

By clicking the System Login button from the screen of FIG. **23**, the USER LOGIN window, as shown in the screen in FIG. **29**, is launched. The user login window comprises fields for providing a username and password and also comprises an on-screen keyboard/pad that allows the operator to supply the required information without the need of a separate keyboard.

By clicking the Visual Operation button shown in FIG. **18**, the screen of FIG. **30** launches. This screen illustrates a dynamic view of the overall system. By clicking on the Parameters button on this screen, the centrifuge statistics appear as shown in FIG. **31**.

At any time during operation, the operator may save current operating inputs in a CUSTOM MODE file, as described previously and shown with respect to FIG. **18**. The operator can then select those pre-saved operating parameters for operation as shown in FIG. **32**, where certain preset operating parameters have been stored as CUSTOM MODE 1.

It should be appreciated that the computer software of the invention, included in a program listing appendix on compact disc, operates the computer, and ultimately controls the associated motors that run the centrifuge. The enclosed software is sufficient in and of itself to enable one having ordinary skill in the art to make the invention, and the screen captures illustrated in the drawing figures are sufficient to enable one having ordinary skill in the art to use the invention. The flow charts included in FIGS. **2–17** are self-explanatory and merely explain in more concise terms the logic and flow of the computer program and motor and pump control.

Thus, it should be apparent that the objects of the invention are efficiently obtained, but it should also be understood that modifications, changes and substitutions are intended in the foregoing, some of which have been specifically described, and that these are intended to be within the spirit and scope of the invention as claimed.

What is claimed is:

1. A centrifuge for centrifuging a slurry, comprising:

a bowl driven by a bowl drive motor;

a screw conveyor driven by a screw conveyor drive motor;

a pump driven by a pump motor;

a bowl drive unit operatively arranged to drive said bowl drive motor;

a conveyor drive unit operatively arranged to drive said screw conveyor drive motor;

a pump drive unit operatively arranged to drive said pump drive motor; and,

a general purpose first computer specially programmed to control said bowl drive unit to drive said bowl drive motor at a first constant speed, to control said screw conveyor drive unit to drive said screw conveyor drive motor at a second constant speed, to compare the respective torques of said bowl drive motor and said screw conveyor drive motor to a torque set point, while simultaneously controlling said pump drive unit to variably control flow of said slurry through said centrifuge in response to a first torque comprising said respective operating torque for whichever of said screw conveyor motor or bowl motor is operating closest to its respective rated torque, wherein variably controlling flow comprises decreasing said flow in response to said first torque being greater than said set point and increasing said flow in response to said first torque being less than said set point.

2. The centrifuge recited in claim **1** wherein said torque set point is a percentage of rated torque.

3. A centrifuge for centrifuging a slurry, comprising:

a bowl driven by a bowl drive motor;

a screw conveyor driven by a screw conveyor drive motor;

a pump driven by a pump motor through a gear box having a gear box ratio and known pump output rate per revolution;

a bowl drive unit operatively arranged to drive said bowl drive motor;

a conveyor drive unit operatively arranged to drive said screw conveyor drive motor;

a pump drive unit operatively arranged to drive said pump drive motor; and,

a general purpose first computer specially programmed to control said pump drive unit to variably control flow of said slurry through said centrifuge in accordance with said gear box ratio and known pump output rate per revolution until such time as the load of said slurry causes one of said bowl drive motor or said screw conveyor motor to exceed an operator set operating torque for said bowl drive motor or said screw conveyor motor, respectively.

4. In a system having a centrifuge comprising a bowl and screw conveyor driven by a bowl motor and screw conveyor motor, respectively, said system also having a feed pump driven by a pump motor through a pump gearbox having a gearbox ratio to provide a slurry load to be centrifuged by said centrifuge, an improved apparatus for controlling said system, comprising:

a. means for manually setting a feed pump gear box ratio and feed pump output rate per revolution for said feed pump;

b. means for manually setting an operating torque set-point for said screw conveyor motor and said bowl motor; and,

c. means for automatically controlling said pump motor to regulate said feed pump until said slurry load demands more than said manually set operating torque for said screw conveyor motor or said bowl motor.

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