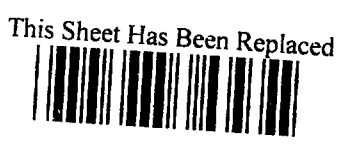


REPLACED SHEET			
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Description

ELEVATOR SPEED DICTATION SYSTEM

Technical Field

5 The present invention relates to elevator systems and in particular to elevator velocity control.

Background Art

10 The need to control the velocity of an elevator is well known. Reference is had, for example, to assignee's U.S. Patent 4,751,984 of Walter L. Williams, Donald G. McPherson & Arnold Mendelsohn entitled "Dynamically Generated Adaptive Elevator Velocity Profile" issued June 21, 1988, as well as to the art cited therein.

15 As noted in the Williams et al. patent, automatic elevator operation requires the control of elevator velocity with respect to zero or stop, at the beginning and the end of a trip, to speeds therebetween, which minimize trip time while maintaining comfort levels and other constraints. The time change in velocity for a complete trip is termed a "velocity profile." Automatic elevator control further requires control of the distance travelled during a trip in order to accomplish a precision stop at the destination floor.

20 Certain velocity profile generation strategies may lead to control instabilities. A common strategy is to use a phase-plane control for precision stopping, wherein dictated velocity is a function of the distance to go to the landing. As the distance-to-go approaches zero, the slope of the velocity/distance curve approaches infinity (∞). Using linear control theory, it can be shown that the slope of the phase-plane curve represents the position error gain for phase-plane control and is proportional to position loop bandwidth. For the speed

control loop to track the dictated velocity profile with stability, its bandwidth must be greater by a significant factor than the bandwidth of the position control loop.

One strategy for reducing the required bandwidth is to limit the slope of the phase-plane velocity versus position profile (position error gain) to a maximum value, such that the position loop bandwidth is sufficiently lower than the velocity loop bandwidth.

Generally, the torque producing capability of elevator motors may vary with speed due to motor current, voltage, and/or power limitations. If the drive is not capable of maintaining the acceleration limit under all conditions due to these torque limits, some means of reducing the acceleration (and hence torque) in the corresponding portions of the velocity profile must be provided without compromising operation of the drive at its limit or complicating the profile generation more than necessary.

To avoid, inter alia, these problems, in Williams et al. each segment of the velocity profile was generated at one of the limits constraining the system; viz., at maximum jerk, maximum acceleration, maximum velocity, maximum position or loop gain, or maximum motor torque. The acceleration portion of the velocity profile preferably was generated in an open loop manner, beginning with constant (maximum) jerk, transitioning to constant (maximum) acceleration after an acceleration limit is attained, and jerking out (negative jerk) at a constant rate to maximum (contract) velocity when the maximum velocity is nearly attained. However, although Williams et al. represented a very substantial advance in the art, it also was subject to improvement, to which the present invention is directed. The disclosure of the Williams et al. patent is incorporated herein by reference.



Disclosure of Invention

In the invention, at a speed close to the base speed of the motor, acceleration reduction preferably is used to keep power requirements well bounded without
5 significantly compromising flight time. This is a form of acceleration profile adaptation based on speed.

Another type of adaptation also may be used. The acceleration and jerk limits for the profile may be adjusted in accordance with available torque. The torque
10 requirements may be determined from the load weighing signal, which gives the load in the cab. The acceleration and jerk limits for the profile can then be adjusted accordingly.

Thus, the profile generator can be made adaptive
15 by presetting the acceleration and jerk limits based on the load in the elevator cab. This can be done by a simple computation based on the load weight made at the beginning of a run. This could be done to permit the use of a smaller than usual drive system, if so desired.

20 The dictation system of the present invention is capable of generating for output high-quality velocity and acceleration signals. It is advantageous because it is highly structured in design, tolerant of significant computational errors, and is easily modified to handle
25 unusual situations.

Therefore, it is an object of the present invention to produce a minimum-time velocity/acceleration profile, subject to the following constraints:

- contract speed(s) (as in Williams et al.);
- 30 ■ ride comfort constraints; i.e., acceleration and jerk limits (as in Williams et al.);
- drive torque and power limits (following to some degree Williams et al.); and
- compatibility with the drive system.





In addition, like Williams et al., the velocity-profile generation approach of the present invention preferably:

■ provides for precision stopping at the
5 destination floor and re-leveling;

■ complies with the code required door zone and other terminal landing speed limits; and

■ accommodates short runs where the contract speed is not reached, as well as very short runs where
10 the "stop control command" (SCC) is reached before the velocity "VBASE" (described more fully below) is reached.

According to the invention and as part of the improvement to the approach of Williams et al., each segment of the velocity profile likewise is generated at
15 one of the limits which constrain the system; viz., at maximum jerk, maximum acceleration, maximum velocity, maximum position or loop gain, or maximum motor torque. The acceleration portion of the velocity profile preferably is generated in an open loop manner, beginning with
20 constant (maximum) jerk, transitioning to constant (maximum) acceleration after an acceleration limit is attained, and jerking out (negative jerk) at a constant rate to maximum (contract) velocity when the maximum velocity is nearly attained.

25 The invention may be practiced in a wide variety of elevator applications utilizing known technology, in the light of the teachings of the invention, which are discussed in detail hereafter.

Some of the technological advances achieved
30 and/or followed in the preferred embodiment of the present invention are outlined below.

1. The velocity is stored in a table as a function of distance gone during acceleration. This table can be used in reverse to find dictation as a
35 function of distance to go during deceleration. The new profile generator explicitly builds the velocity table

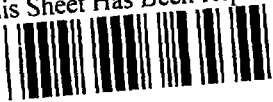


from acceleration and jerk constraints. This means that acceleration corresponding to each velocity is known. The new profile generator stores acceleration information along with velocity information in tables having distance as the independent variable. Table entries are made during each processor cycle during acceleration. The acceleration table is used in reverse together with a numerical scaling to decelerate the elevator. Acceleration information is output by the profile generator at all times (acceleration, constant speed, deceleration). No numerical differentiation of velocity is used to find acceleration, except in special situations. This results in a high-quality acceleration signal. Also, processor time is saved.

2. The acceleration signal mentioned in "1" above can be blended with the velocity signal and the combination applied as dictation to a drive. This provides an "acceleration feedforward" that reduces velocity tracking time and thus makes the drive more responsive. The acceleration signal can also be applied in standard fashion to the torque input point of a drive (if available). A disadvantage of feedforward is that it makes the drive system more load sensitive. Load sensitivity can be compensated for, if a load weight signal is available. This may be accomplished by varying the proportional gain of the proportional-integral controller used in the drive as a function of load weight.

3. The new profile generator has a simple algorithm for computing stopping distance. The algorithm can be used for runs of all lengths. The stopping distance is computed based on the DICTATED profile.

4. The stopping distance in "3" is compared to DISTTG (distance to go; DRIVE OUTPUT COORDINATES) converted to DICTATION coordinates. The conversion is accomplished by subtracting the tracking distance error



from DISTTG. In the new profile generator the distance error is not entered in terms of drive tracking delay and velocity. Instead, the actual, MEASURED, distance tracking error is used. The measurement is accomplished
5 by using numerical integration of dictated velocity to find distance dictated. The

$$\begin{aligned}\text{DISTANCE GONE} &= \text{LENGTH OF RUN} - \text{DISTTG, and} \\ \text{DISTANCE DICTATED} - \text{DISTANCE GONE} &= \text{DISTANCE} \\ &\text{TRACKING ERROR.}\end{aligned}$$

10 The stop control command (SCC) is issued when the following condition is true:

$$\begin{aligned}\text{STOPPING DIST.} &\geq \text{DISTTG} - \text{DIST. ERROR} - \\ &(\text{2} * \text{VEL} * \text{DELTAT})\end{aligned}$$

STOPPING DIST. is computed; DISTTG (distance to go) comes
15 from a position transducer; DIST. ERROR is also measured; and the last term accounts for two cycles of delay in the processor system. VEL is dictated velocity and DELTAT is the processor cycle time (10-40 ms is typical).

5. The stop control command as defined in "4"
20 usually cannot be issued perfectly. The distance range applicable to the velocity and acceleration tables will not match the distance to go. This problem becomes especially severe when the elevator is to be decelerated with look-ahead-distance-to-go (LADTG) rather than DISTTG
25 as the independent variable. The problem is solved in the new profile generator by the introduction of a MULTIPLIER. This multiplier is a scaling factor that acts on the LADTG to make it equal to the distance range for the velocity and acceleration tables. Usually the
30 MULTIPLIER is a number very close to one (1.0) for long runs. It may deviate significantly from one (1.0) for very short runs because of numerical errors. The MULTIPLIER assures that numerical errors, timing delays, etc., will not cause bizarre phase plane trajectories.
35 The phase plane-control in the profile generator of the



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invention is self-correcting and robust because of the MULTIPLIER.

6. The look-ahead-distance-to-go (LADTG) is made adaptive in the new profile generator. It is not used for runs of less than 1000 mm (pure DISTTG is used). Further, as the end of a run is approached, LADTG has a "washout" term which is a function of DISTTG. As DISTTG approaches zero, a multiplier acts on the velocity dependent portion of LADTG to make that term less and less significant. Should the control overshoot and the DISTTG go negative, phase plane control reverts to pure DISTTG, rather than LADTG as the independent variable.

7. The profile design is modular, structured, and deterministic. Acceleration, jerk, and distance constraints permitting, it is capable of being altered after a run has begun. The modular design makes design modifications relatively easy. Maintenance of the code and teaching of the design to new engineers is not complicated.

8. The profile generator can be made adaptive by presetting the acceleration and jerk limits based on the load in the elevator cab. This is done by a simple computation based on load weight made at the beginning of a run. This could be done to permit use of a smaller than usual drive system. Working of examples indicates that significant cost savings are possible with little degradation in overall service (traffic flow).

Other features and advantages will be apparent from the specification and claims and from the accompanying drawings, which illustrate two exemplary embodiments of the invention.

Brief Description of Drawings

Figure 1 is a simplified, block diagram of an exemplary embodiment of the elevator speed dictation system of the present invention.

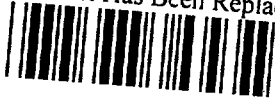


Figure 2 is a graph of the velocity profile of the invention for an exemplary long run of an elevator car in accordance with the exemplary principles of the present invention. (It is noted that the numerical information on the lower, right side of the figure refers to the data values of the traces at the vertical cursor line located to the left side of the graphed, displayed traces; the same being true of Figs. 3-6.)

Figure 3 is a flow chart showing the transitions between the regions of the velocity profile of Figure 2, as well as of the velocity profiles of Figures 4-6, with Regions 0 (zero speed) and 1 (low level phase plane) not being illustrated for simplicity purposes in the velocity profiles.

Figure 4 is a graph of the velocity profile of the invention for an exemplary "Intermediate II" profile of the elevator car, in which the Intermediate II profile illustrates the situation wherein a transition to Region 5 occurs after a Stop Control Command (SCC).

Figure 5 is a graph of the velocity profile of the invention for an exemplary "Intermediate I" profile of the elevator car, in which the Intermediate I profile illustrates the situation wherein there is a transition from Region 3 to Region 5.

Figure 6 is a graph of the velocity profile of the invention for an exemplary short run of the elevator car.

Figure 7 is a comparative graph of exemplary velocity and acceleration curves used in the invention to find the stopping distance.

Best Modes for Carrying Out the Invention

As noted in Williams et al., in order to provide rapid, controlled and smooth motion control in an elevator, a velocity profile is generated which observes constraints regarding jerk, acceleration and equipment



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limitations. Typical, exemplary requirements for a high performance system are:

	RISE	-	up to 400 M
	LOADS	-	900 TO 3600 KG
5	SPEEDS	-	2.5 to 10 M/S
	ACCEL.	-	up to 1.5 M/S
	JERK	-	up to 3.0 M/S
	LEVELING	-	± 0.006 M

An exemplary function block diagram of the invention is shown in Figure 1. The profile generator (PROFILE GEN.) delivers a velocity signal "VD" and an acceleration signal "AD" to an elevator control system. The gain "KA" is used to control the blend of the acceleration signal to the velocity signal in a feed-forward control. Alternatively, the acceleration signal may be routed directly to the motor torque control point in the motor drive.

Sometimes limiters or filters (not illustrated) are used between the VD and AD signals and the elevator motion system ("EMS"). The EMS includes a position reference system, which feeds back the car position ("POSITION") to the profile generator.

The function of the profile generator is to bring the car to the target position within the acceleration and jerk constraints. These constraints may be fixed or they may be a function of available power, motor torque, etc. Just before and sometimes even during a run, the constraints may be changed. The profile generator is designed in a structured fashion, thereby permitting adaptation to changing circumstances, even when a run is under way.

The overall position control system should bring the car to its destination in a minimum amount of time, without vibrations or overshoot. The overall positioning accuracy sought is usually better than plus-or-minus



three millimeters (± 3 mm), although plus-or-minus six millimeters (± 6 mm) is acceptable.

The acceleration limit is usually set by the available torque in the motor drive. However, in an oversized system, passenger comfort may determine the acceleration limit.

In many systems the passenger comfort acceleration sets the acceleration with the motor torque limitation becoming a problem, only when the cab is empty or fully loaded. Most high-performance elevator systems are equipped with a load-weighing system.

Knowledge of elevator system parameters and the load weight permits computation of the maximum allowed acceleration based on the motor torque limit. Those skilled in the elevator art may routinely make this calculation, which is based on the mass of the hoistway equipment, the overbalance used for the counterweight, the load in the cab, and the available motor torque.

Part of the torque is used to offset unbalance and friction forces. The other part is used to accelerate or decelerate the system mass.

The profile construction strategy of the invention will now be described first in terms of typical profiles produced by the exemplary apparatus of the invention.

Figure 2 shows the dictated and actual velocity and acceleration for an exemplary long run. Understanding this profile set is important because all other profile sets are subsets of this one. As can be seen in Figure 2 various regions 2-7, defined and explained more fully below, are marked.

The profiles for the first part of the run are developed on the basis of dictated acceleration. Dictated velocity is obtained by the numerical integration of the dictated acceleration. (Henceforth, as a matter of form and for simplicity purposes, dictated



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velocity and acceleration typically will be referred to without the adjective "dictated" being added.) The actual position, velocity, and acceleration are outputs from the EMS.

5 It is noted that the quantity target position - position = distance-to-go ("DISTTG"). A greatly amplified trace of "DISTTG" 50 is shown in Figure 2.

The regions in Figure 2 are defined as follows and illustrated in block form in Figure 3:

10	<u>Region</u>	<u>Definition</u>
	0	zero speed
	1	low level phase plane
	2	constant jerk to prescribed acceleration
15	3	prescribed acceleration
	4	constant jerk down to constant velocity
	5	jerk level after generation of SCC
	6	constant speed
20	7	phase plane

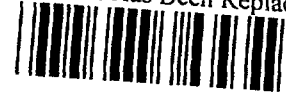
Regions "0," "1," and "7" apply to runs of all lengths. Regions 0 and 1 are not shown explicitly on the profiles illustrated in Figures 2, etc., and the meaning of Region 1 is explained when the phase-plane Region 7 is explained.

25 In the profiles of Figure 2 and Figures 4-6, the profile traces and the parameters they represent are tabulated below:

	<u>Trace #</u>	<u>Parameter</u>
30	10	velocity
	20	velocity dictation
	30	acceleration
	40	dictated acceleration
	50	distance to go (greatly magnified)

35 Figure 2 will now be discussed on a time-history basis. The elevator car is stopped. It then accelerates at "constant jerk" in Region 2 until the acceleration limit is reached.

40 The end of Region 3 is defined when "VBASE" is reached. "VBASE" can be the base velocity or speed of the motor or a lower speed. "VBASE" is subject to some



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variation, and, typically, it will be close to but a bit less than the base speed of the motor involved. A "jerk out" is then defined in Region 4 until maximum speed is reached in Region 6. Operation continues in Region 6,
5 until the stop control command (SCC) is received.

Region 7 is then entered. In that region the velocity is commanded as a function of distance-to-go on the basis of a table of velocity versus distance built up for all travel in Regions 2-5. At the time the velocity
10 table is being built, an acceleration table is also being built. Both the velocity and acceleration tables can be weighted, so that deceleration occurs in direct proportion to a set "DECELRTIO." The "DECELRTIO" is usually less than one (<1.0), but it may also be larger than one
15 (>1.0).

The profile generator regions are illustrated in block form in Figure 3. The transitions from Regions 1 to 0 and 0 to 1 are used at the beginning of a run for holding the elevator at the floor when the brake is
20 lifted and the transition to Region 2 is about to commence. Upon receipt of SCC, it is possible to leave Regions 2-4 and enter Region 5.

Deceleration of the elevator occurs in Region 7 using a phase-plane control. The dictated velocity and
25 acceleration used are retrieved from tables built in Regions 2-5. When the elevator has almost landed or during recovery from an overshoot, the low-level phase plane Region 1 is entered. The low-level-phase plane has a linear slope (velocity/DISTTG) in a range of, for
30 example, one to four ($1-4 \text{ sec}^{-1}$) 1/second.

Actual operation for less than full-length runs is illustrated in Figures 4-6. Figure 4 is termed "Intermediate II" because the transition to Region 5 occurs after SCC. Figure 5 is an "Intermediate I" profile because a transition occurs from Region 3 to
35 Region 5. This figure illustrates the typical operation



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for a one-floor run. Figure 6 is a short run in which the acceleration limit, Region 3, is not reached, and, thus, transition occurs directly from Region 2 to Region 5.

5 Proper operation of the profile generator system requires careful attention to detail, especially if smooth, error tolerant operation is desired. These details are described below.

- Major Operations in Profile Generation -

10 The timed portions of the profiles are obtained by successive numerical integrations using the trapezoidal algorithm. This has the following general form:

$$X_n = X_{n-1} + (T/2)(dX_n/dt + dX_{n-1}/dt)$$

where -

15 X_{n-1} is the previous value of X_n
(Computed at time $t_{n-1} = t_n - T$); and
T is the step size (cycle time, sampling rate).

The major operations other than generation of a
20 timed profile are listed here. Those occurring in Regions 2-6 are:

1. Build the linear portion of the phase-plane table.
2. Build the phase-plane table in regions
25 2-5.
3. Compute the stopping distance (Regions 2, 3, 4, 6).
4. Determine the distance error and SCC.

The following operations are important in transitioning to, and operating in, Region 7 (phase plane):
30

1. Determine the "MULTIPLIER" for coordinate transformation.
2. Compute the Look-Ahead-Distance-To-Go ("LADTG") from DISTTG.
- 35 3. Interpolate the velocity and acceleration tables.



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4. Transition to low-level phase plane at the end of the run.

Details of the foregoing operations are discussed below.

5

- Phase Plane Table Building -

The phase plane table is built dynamically in a microprocessor during the timed acceleration portion of the profile. As the acceleration and velocity dictation signals are computed each cycle, they are stored in a table together with the index and a corresponding distance. The table is built to satisfy the profile requirements in the phase plane deceleration region. At low speeds where $VD \leq LEVELVEL$ (elevator approaches the destination), the relationship between the dictated velocity and the distance-to-go is linear -

$$VD = K * DISTTG$$

The corresponding dictated acceleration is calculated as -

$$AD = K * VD$$

20 where K is the position loop gain (see Fig. 1). For standard profiles -

$$K = LEVELGAIN$$

For speeds where $VD > LEVELVEL$, the relationship between VD and DISTTG is nonlinear. The acceleration, velocity, and position entries in the table are obtained by successive integrations, and the table index is incremented each cycle.

Taking the DECELRTATIO factor into account, the equations used for table building are:

30 If $VD_n \leq LEVELVEL$

then -

$$INDEX = n$$

$$VTBL(n) = VD_n$$

$$XTBL(n) = VD_n \div K$$

35 $ATBL(n) = VD_n * K$



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However -

if $VD_n > LEVELVEL$
then -

5 INDEX = n
VTBL(n) = VD_n
ATBL(n) = $\frac{1}{2} * [ATBL(n-1) + AD_n * DECEL RATIO]$
XTBL(n) = $XTBL(n-1) +$
 $+ \frac{1}{2}T * [VTBL(n-1) + VD_n] \div$
DECEL RATIO

10 where -

$$LEVELVEL = AD_n * DECEL RATIO \div K$$

Table building continues until the acceleration reaches zero, or, in other words, it is stopped for one of two reasons:

- 15 (1) Region 7 (phase-plane) is entered without going through Region 6 (constant velocity); or
(2) a transition is made to Region 6.

- Stopping Distance and SCC Determination -

20 Besides table building, computations preferably are being made during acceleration to determine the stopping distance based on the dictation. This stopping distance is correct if no time delays exist in the velocity control system.

25 The following basic equations applied to Figure 7 are used to compute the stopping distance when Region 6 (constant velocity) is not entered:

$$\begin{aligned} JD_n &= J_0 \\ AD_n &= A_0 + J_0 * t \\ VD_n &= V_0 + A_0 * t + \frac{1}{2} * J_0 * t^2 \\ 30 \quad XD_n &= X_0 + V_0 * t + \frac{1}{2} * A_0 * t^2 + \frac{1}{6} * J_0 * t^3 \end{aligned}$$

where -

JD_n , AD_n , VD_n and XD_n are the current dictated, jerk, acceleration, velocity and distance, respectively (at time $t = t_n$); and J_0 , A_0 , V_0 and X_0 are the initial
35 jerk, acceleration, velocity and distance, respectively.



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If the SCC command is generated during the constant velocity portion (Region 6), then the stopping distance is determined only by the current distance stored in the table. Otherwise, the stopping distance is given, after some derivation, by:

$$\begin{aligned} \text{STOP.DIST} = & \text{XTBL}(n) + \\ & + (\text{VD}_n * \text{AD}_n / \text{J}_0 + 1/3 * \text{AD}_n^3 / \text{J}_0^2) * (1 + \\ & + 1/\text{DECEL RATIO}) \end{aligned}$$

The stopping distance must be compared not to the actual distance-to-go but to that value corrected for delays. The following equality defines the stop control command (SCC) point, when processor system delays are neglected.

$$\text{STOP.DIST} = \text{DISTTG} - \text{DIST.ERR.}$$

where -

$$\text{DISTTG} = \text{TARGET.POS} - \text{CURRENT.POS}$$

$$\text{DIST.ERR} = \text{DIST.DICT} - \text{DIST.GONE}$$

$$\text{DIST.GONE} = \text{CURRENT.POS} - \text{STARTING.POS}$$

The dictated distance "DIST.DICT" is computed by integrating the dictated velocity, "VD_n":

$$\text{DIST.DICT} = \text{XD}_n = \text{XD}_{n-1} + [\text{VD}_n + \text{VD}_{n-1}] * \frac{1}{2} T$$

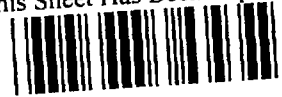
In a real system implementation, the information processing delays in the position loop become significant and must be compensated. The equality given above for "STOP.DIST" is modified as indicated for implementation in a real system:

$$\text{STOP.DIST} \geq \text{DISTTG} - \text{DIST.ERR} - n * \text{VD} * T$$

The number $n = 2$ is usually used to account for a delay of two processor cycles.

- Phase Plane Deceleration of Elevator -

In the phase plane region, a linear interpolation technique preferably is used to calculate the acceleration and velocity signals from the previously constructed tables. The distance-to-go to the target landing is used to index the tables.



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Table building and determination of SCC have been described to this point. The matter of transitioning to Region 7 (phase plane) will now be addressed. At the transition to Region 7, the dictated velocities are
5 inherently matched ($AD = 0$).

Distances, however, may not be matched, especially since a coordinate transformation is introduced. Distance control is shifted from distance-to-go to Look-Ahead-Distance-To-Go (LADTG). The LADTG used here
10 is a variant of a similar quantity described in the Williams, et al. Patent 4,751,984, referred to above.

LADTG as defined below is used for the proper operation of the phase plane control, especially as the target landing is approached. The $RATIO$ is used to blend
15 LADTG into DISTTG at the target landing. The $VD_{n-1} * T_c$ term is identical to that of Williams, et al. The $MULTIPLIER$ is used to assure that LADTG matches the last distance entry stored in the phase plane tables.

$$LADTG = (DISTTG - COMPENSATION) * MULTIPLIER$$

20 where -

$$COMPENSATION = VD_{n-1} * T_c * RATIO$$

T_c - approximates the position loop delay and is a constant, which is adjustable in the EMS.

As the dictated velocity decreases to zero,
25 LADTG approaches the value of DISTTG. The rate at which the $COMPENSATION$ term is reduced to zero is further controlled by the $RATIO$ factor.

As the elevator approaches the destination floor, the value of $RATIO$ must be gradually reduced ("washed-
30 out") from one to zero (1 to 0). Consequently, $RATIO$ is defined as follows:

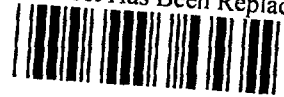
If $DISTTG > WDIST$

then $RATIO = 1$, else $RATIO = DISTTG \div WDIST$,

where "wash-out distance" ($WDIST$) is:

$$WDIST = LEVELVEL \div LEVELGAIN$$

35



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A linear definition is given here for RATIO. However, a nonlinear definition may be more useful in some circumstances. This is illustrated in the programmed simulation discussed below.

5 The MULTIPLIER is calculated only once, as the profile enters the phase plane deceleration region. It then remains constant until the end of the run.

$$\text{MULTIPLIER} = \text{XTBL}(M) \div \text{DISTTGT}$$

where -

10 XTBL(M) - is the last distance stored in the table, and

DISTTGT - is the actual distance-to-go at the transition point.

At the transition to the phase plane, LADTGT is
15 forced to match the last phase plane entry:

$$\text{LADTGT} = \text{XTBL}(M)$$

Subsequently computed LADTGs are then scaled by the value of the MULTIPLIER, as shown above.

For best deceleration control, MULTIPLIER values
20 close to unity or one (1.0) are desirable.

The dictated acceleration AD and velocity VD are calculated from the phase plane table using a linear interpolation technique. LADTG is used as an indexing reference.

$$\begin{aligned} 25 \quad AD &= \{A - [(X - \text{LADTG}) \div (X - X1)] \\ &\quad * (A - A1)\} * \text{MULTIPLIER} \end{aligned}$$

$$VD = V - [(X - \text{LADTG}) \div (X - X1)] * (V - V1)$$

where -

$$A = \text{ATBL}(n), \quad V = \text{VTBL}(n), \quad X = \text{XTBL}(n)$$

$$30 \quad A1 = \text{ATBL}(n-1), \quad V1 = \text{VTBL}(n-1), \quad \text{and}$$

$$X1 = \text{XTBL}(n-1)$$

After the entries in the phase table are almost used up, a linear phase plane trajectory is used based on LADTG. If an overshoot occurs, similar control is used
35 and DISTTG is used rather than LADTG. The equations



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applicable after leaving the phase plane table but before the target landing are:

$$VD = LADTG * K$$

$$AD = - VD * K * MULTIPLIER$$

5 where K = the position loop gain.

If the target landing is overshoot, then Region 1 (low-level phase plane) is entered to bring the car back to the landing. However, the acceleration signal, if used for feed-forward control, is modified after the zero crossing. "AD" should either be set to zero or computed by the numerical (time) differentiation of VD:

$$AD = [VD(n) - VD(n-1)] \div T$$

where T = cycle time of processor.

- Profile Simulation -

15 An exemplary simulation for the profile generating system written in BASIC (Microsoft's "QuickBASIC 4.0") is presented below. In the program graphics routines used with the simulation are unnecessary for this disclosure and have been removed for purposes of simplicity. The BASIC used here is structured and reads very much like ordinary English or math statements (i.e., / = divide; * = multiply; ^ = exponent; etc.). "Quick BASIC" allows simple calls to subroutines. Also, program control may be shifted by a "GO TO" to a named label.

25 As can be seen, the first part of the program consists of declarative statements and comments. Next, parameters for the profile are set and preliminary computations are made. This type of operation can take place adaptively in a real elevator control to adjust for changing conditions.

30 Variables are initialized and flags are set. Similar operations occur in the control code used to run an elevator.

The distance for the profile is entered.



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The block of code called "READ PHASE PLANE TABLE" is bypassed, and control shifts to a point labeled "TIMED.PROFILE." Profile generation takes places on a region by region basis as described previously. "VD" and
5 "AD" are found by numerical integration. Building of the phase-plane tables takes place next. There are then operations to find the dictated distance, "DIST.DICT," by numerical integration and the distance error, "DIST.ERR."

Next, the stopping distance is found by a call to
10 the subroutine called "STOPD." Then a check is made if $SCC\% = 1$, meaning a stopping sequence should be initiated. The "SCC" determination is based on "DISTTG," as computed below, "DIST.ERR," and the dictated velocity "VD."

15 Control then shifts to the label "VELCONTROL:" . The subroutine "VELCONTROL" is called to simulate in simplified form the operation of the EMS of Figure 1 (a model of a DC drive may be used). This subroutine provides an update to the actual velocity and acceleration.
20 tion. Importantly, it provides the "DIST.GONE" (actual distance traveled by the elevator). From "DIST.GONE" the "DISTTG" is computed.

The simulation continues with a timed-based profile being generated until $SCC\% = 1$. The stopping
25 sequence then commences. For other than a long run, this includes further operation with a timed profile, until a condition of zero acceleration is reached. This is analogous to operation in Region 5, which is commented as "SCC ACTIVE".

30 When $AD = 0$, control shifts to the label near the beginning of the program entitled "PP.PROFILE" - READ PHASE PLANE TABLE." The distance range for the tables is first matched to the "LADTG" (found by a call to a subroutine). The match is made using the parameter
35 called "MULTIPLIER." The "MULTIPLIER" is computed only once during a run. Next, reading of the velocity and



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acceleration tables occurs, using an interpolation algorithm.

The phase plane changes to a straight line definition when the table index $N\% = 1$ (table exhausted).

- 5 A region called "LOWLEV.PROFILE" is then defined. The simulation differs from the actual profile generator in that Region 1 here applies only to the end of the run and that the same phase-plane slope is used for table continuation and for recovery from overshoots.



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- EXEMPLARY BASIC PROGRAM -

```

DECLARE SUB LADISTANCE (LADTG, MULTIPLIER, RDISTANCE,
  distance, VD, DISTTG, DELTATC, LOWLEV%)
DECLARE SUB VELCONTROL (VDICT!, AM!, VM!, XM!, DT!, T!,
5  RESETFLAG%, DRIVELIM)
DECLARE SUB STOPD (XSTART, VSTART, AD, XSTOP, VMAX,
  DECELRTATIO, JERK)
  TITLE: NEWVEL
  COPYRIGHT: OTIS ELEVATOR COMPANY
10  DATE WRITTEN: 2/15/88
  LANGUAGE: QUICK BASIC 4.0
  PURPOSE: SIMULATE NEW MCSS NORMAL PROFILE GENERATOR
15  ***** ARRAYS FOR PHASE PLANE TABLE IN MAIN MODULE
  DIM PPV(600), PPS(600), PPA(600)
  ***** ARRAYS FOR GRAPHING SUBROUTINE GRAFI
20  DIM PARR(4, 600), SF1(4), SF(4), GAIN(4)
  ***** INIT SCREEN, SET SCREEN TYPE TO 2 (CGA), 9 (EGA),
  OR 10 (MONO)
25  CLS : SCREEN 0, 0, 0: COLOR 7, 0, 0: KEY OFF: SCRN = 9
  ** SET PARAMETERS FOR PROFILE AND COMPUTE RELATED VALUES
30  ACCELLIMIT = 1200 'ACCELERATION LIMIT
  JERKLIMIT = 2400 'JERK LIMIT DURING ACCELERATION
  DECELRTATIO = 1! 'RATIO OF DECELERATION TO ACCELE-
  TION
  VELLIMIT = 6000 'MAX SPEED, CONTRACT VELOCITY, ETC.
35  LEVELGAIN = 3! 'LEVELING GAIN (POSITION LOOP GAIN)
  DELTAT = .04: DELTATC = .1: 'CYCLE TIME AND TIME DELAY
  IN VELOCITY CONTROL
  STOPTOLV = 40: STOPTOLS = 6: 'THESE DEFINE CONDITION FOR
  BRAKE DROP
40  VELLIMIT1 = 1.01 * VELLIMIT 'USED FOR SPEED CHECK
  VBASE = 4800 'VELOCITY AT WHICH ACCELERATION IS REDUCED
  AT JERKBASE RATE
  VBASE<VELLIMIT TO BE EFFECTIVE
  DELTAACCELS = JERKLIMIT * DELTAT / 2 'ACCEL. INCRE. FOR
45  TESTING ACCEL.
  REDUCTION
  ***** INITIALIZE VARIABLES AND SET FLAGS
  REGION% = 2 ' START RUN IN REGION 2
50  RESETFLAG% = 1 ' CAUSE VELCONTROL SUBROUTINE TO INITIAL-
  IZE ON FIRST PASS
  TSTOP = 999 ' FLAG AND REGISTER FOR STOPPING. TIME
  WITHIN STOPTOLS AND STOPTOLV

```



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```

      VD = 0: AD = 0 ' INITIAL DICTATED VELOCITY AND ACCELERA-
      ' TION
      BUILD.TABLE% = 1 ' TABLE IS BUILT WHEN RUN STARTS UNTIL
      ' AD = 0
5     READ.TABLE% = 0 ' TABLE IS READ DURING PHASE PLANE
      ' DECELERATION TO LANDING
      SCC% = 0 ' STOP CONTROL COMMAND = 1 STARTS
      ' STOPPING SEQUENCE
10    DIST.GONE = 0 ' START AT ZERO POSITION
      CLOCK = 0 ' START AT ZERO TIME
      PPI% = 0 ' INITIAL INDEX FOR TABLE
      PPV(PPI%) = 0: PPS(PPI%) = 0: PPA(PPI%) = 0 ' INITIAL
      ' VALUES OF
      ' TABLE
15    MATCHFLAG% = 1 ' FLAG TO COMPUTE MULTIPLIER ON FIRST PASS
      ' READING TABLE
      MULTIPLIER = 1 ' USED FOR PERFECT MATCH OF VELOCITY TABLE
      ' TO CURRENT VELOCITY
      LOWLEV% = 0 ' LOWLEVEL PHASE PLANE WHEN LOWLEV%=1,
20    ' NO LOWLEVEL OTHERWISE
      LLTIME% = 0 ' FLAG TO CAPTURE START OF LOW LEVEL
      ' OPERATION
      VELMAXFLAG% = 0 ' FLAG TO CONTROL PROFILE WHERE VELMAX(SUB
      ' STOPD) DETERMINES SCC
25    distx = 0
      '
      ' BRAKE LIFTED AT START OF RUN; BRAKE DROPPED AT T=FLTIME
      '
      ' ***** PARAMETERS REQUIRED FOR GRAF1 SUBROUTINE
30    '
      SP = 1: FOR I = 0 TO 3: GAIN(I) = 1: NEXT I: GAIN(4) =
      100
      XSCALE = 1: XSTART = 0
      FOR I = 0 TO 4: PARR(I, 0) = 0: NEXT I
35    '
      ' SCREEN PRINT OF PARAMETERS AND INPUT OF RUN DISTANCE
      '
      LOCATE 10, 1: INPUT "DISTANCE FOR RUN (mm) (3653 mm
40    default)= "; distance
      IF distance = 0 THEN distance = 3653
      DISTTG = distance
      RUN.DISTANCE = distance
      LOCATE 12, 1: PRINT "DISTANCE FOR RUN = ", distance
45    '
      GOTO TIMED.PROFILE
      ' ***** GOTO TIMED PROFILE *****
50    PP.PROFILE:
      ' ***** READ PHASE PLANE TABLE *****
      '
      IF READ.TABLE% = 0 THEN
          GOTO TIMED.PROFILE

```



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```

ELSEIF LOWLEV% = 1 THEN
    GOTO LOWLEV.PROFILE
END IF
'
5  ' READ VELOCITY AND ACCELERATION FROM PHASE PLANE TABLE
    '
    BUILD.TABLE% = 0

    ' GO COMPUTE LADTG
    '
10  CALL LADISTANCE(LADTG, MULTIPLIER, RDISTANCE, distance,
    VD, DISTTG, DELTATC, LOWLEV%)
    '
    'MATCH OF TABLE TO LADTG
    '
15  IF MATCHFLAG% >= 1 THEN
        MULTIPLIER = PPS(PPI%) / LADTG
        MATCHFLAG% = 0
        LADTG = PPS(PPI%)
    END IF

20  '
    '
    DO UNTIL PPS(PPI% - 1) <= LADTG
        PPI% = PPI% - 1
        IF PPI% <= 1 THEN
25          LOWLEV% = 1
            GOTO LOWLEV.PROFILE
        END IF
    LOOP
    '
    '
30  SRATIO = (PPS(PPI%) - LADTG) / (PPS(PPI%) - PPS(PPI% -
    1))
    VD = (PPV(PPI%) - (PPV(PPI%) - PPV(PPI% - 1)) * SRATIO)
    AD = -(PPA(PPI%) - (PPA(PPI%) - PPA(PPI% - 1)) * SRATIO)
35  * MULTIPLIER
    '
    '
    GOTO VELCONTROL
    '***** GOTO VELCONTROL SIMULATION *****'
    '
40  '
    LOWLEV.PROFILE:
    '***** CONTINUE PHASE PLANE AT END OF RUN *****'
    '
    CALL LADISTANCE(LADTG, MULTIPLIER, RDISTANCE, distance,
45  VD, DISTTG, DELTATC, LOWLEV%)
    '
    VD = LADTG * LEVELGAIN
    AD = -VD * LEVELGAIN * MULTIPLIER
    '
50  GOTO VELCONTROL
    '***** GOTO VELCONTROL SIMULATION *****'
    '
    '

```



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```

TIMED.PROFILE:
'***** GENERATE TIMED PROFILE DURING AD AND *****
'***** WHILE RUNNING AT CONTRACT (CONSTANT) SPEED *****
'
5  ON REGION% GOTO REGION2, REGION2, REGION3, REGION4,
    REGION5, REGION6
    '
    '
REGION2:          'START HERE --- JERK IS CONSTANT
10  '
    JERK = JERKLIMIT
    '
    '***** VERY LOW SPEED PROFILE SETS VELMAXFLAG% *****
    '***** (VELMAX COMES FROM STOPPING DISTANCE SUB-
15  '          -ROUTINE) *****
    '
    IF VELMAX >= VELLIMIT - AD * DELTAT THEN
        VELMAXFLAG% = 1
        REGION% = 4
20  GOTO REGION4
    END IF
    '
    IF AD >= ACCELLIMIT THEN
        REGION% = 3
25  GOTO REGION3
    ELSEIF SCC% = 1 THEN
        REGION% = 5
        GOTO REGION5
    END IF
30  GOTO START.INTEG
    '
REGION3:          'CONSTANT ACCELERATION
    '
    JERK = 0
35  AD = ACCELLIMIT
    '
    IF VELMAX >= VELLIMIT - AD * DELTAT THEN
        VELMAXFLAG% = 1
        REGION% = 4
40  GOTO REGION4
    END IF
    '
    IF VD >= VBASE THEN
        REGION% = 4
45  GOTO REGION4
    ELSEIF SCC% = 1 THEN
        REGION% = 5
        GOTO REGION5
    END IF
50  GOTO START.INTEG
    '
REGION4:          'HIGH SPEED ACCELERATION REDUCTION
    '
    '***** COMPUTE JERK DYNAMICALLY *****

```



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```

JERK = -AD ^ 2 / (2 * (VELLIMIT - VD))
DELTAACCEL = -JERK * DELTAT / 2
'
5  IF VD >= VELLIMIT1 OR AD <= DELTAACCEL THEN
    REGION% = 6
    BUILD.TABLE% = 0
    DIST.ERRMAX = DIST.ERR
    GOTO REGION6
10  ELSEIF SCC% = 1 THEN
    REGION% = 5
    GOTO REGION5
    END IF
    GOTO START.INTEG
15  '
    REGION5:          'SCC ACTIVE
    '
    JERK = -JERKLIMIT
    '
20  IF AD < DELTAACCELS THEN
    JERK = 0
    AD = 0
    READ.TABLE% = 1
    BUILD.TABLE% = 0
25  END IF
    GOTO START.INTEG
    '
    REGION6:          'RUN AT CONTRACT SPEED
    '
30  JERK = 0
    AD = 0
    VD = VELLIMIT
    IF SCC% = 1 THEN
        READ.TABLE% = 1
35  GOTO PP.PROFILE
    END IF
    '
    START.INTEG:
    '***** FIND DICTATED AD AND VD FROM JERK *****
40  LOCATE 17, 1: PRINT "REGION = ", REGION%, SCC%,
    DIST.GONE
    '
    PREVA = AD
    AD = AD + JERK * DELTAT
45  IF AD > ACCELLIMIT THEN AD = ACCELLIMIT
    IF AD < 0 AND READ.TABLE% = 0 THEN AD = 0
    VD = VD + ((AD + PREVA) / 2) * DELTAT
    '
    '***** BUILD PHASE PLANE TABLE DURING ACCELERATION *****
50  '
    IF BUILD.TABLE% = 1 THEN
        PPI% = PPI% + 1
        PPV(PPI%) = VD
    ELSEIF READ.TABLE% = 1 THEN

```



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```

      GOTO PP.PROFILE
ELSE
      GOTO STOPDIST
END IF
5  '
  '***** BUILD TABLE ON STRAIGHT LINE TRAJECTORY -
  '      - TEST FOR LOW SPEED PROFILE *****
  '
  LEVELVEL = (DECELRTIO * (AD + J * DELTAT)) / LEVELGAIN
10  RDISTANCE = LEVELVEL / LEVELGAIN' DISTANCE FOR WASHOUT
  RATIO IN LADTG
  IF PPV(PPI%) < LEVELVEL AND SCC% = 0 AND VELMAXFLAG% = 0
  THEN
    PPS(PPI%) = PPV(PPI%) / LEVELGAIN
15    PPA(PPI%) = PPV(PPI%) * LEVELGAIN
  ELSE
    PPS(PPI%) = PPS(PPI% - 1) + (PPV(PPI%) + PPV(PPI% -
  1)) * DELTAT / (2 * DECELRTIO)
    PPA(PPI%) = (AD * DECELRTIO + PPA(PPI% - 1)) / 2
20  END IF
  '
  DIST.DICT = DIST.DICT + (PPV(PPI%) + PPV(PPI% - 1)) *
  DELTAT / 2
  DIST.ERR = DIST.DICT - DIST.GONE
25  '
  STOPDIST:
  '***** FIND STOPPING DISTANCE TO DETERMINE SCC *****
  '
  IF SCC% <> 0 THEN GOTO VELCONTROL
30  '
  ' COMPUTE STOPPING DISTANCE
  '
  IF REGION% = 6 THEN
    STOPDIST = PPS(PPI%)
35    DIST.ERR = DIST.ERRMAX
  ELSE
    CALL STOPD(PPS(PPI%), VD, AD, STOPDIST, VELMAX,
  DECELRTIO, -JERKLIMIT)
  END IF
40  ' CHECK FOR STOP CONTROL POINT
  '
  IF STOPDIST >= DISTTG - DIST.ERR - 2 * DELTAT * VD THEN
    SCC% = 1
45  ELSE
    SCC% = 0
  END IF
  '
  VELCONTROL:
50  ' ***** SIMULATE VELOCITY CONTROL SYSTEM *****
  '
  ' SIMULATE VELOCITY CONTROL (DC-DBSS)
  '

```



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```

CALL VELCONTROL(VD, AM, VACTUAL, DIST.GONE, DELTAT,
CLOCK, RESETFLAG%, DRIVELIM)
DISTTG = distance - DIST.GONE
'
5 LOCATE 20, 1: PRINT USING "ELAPSED TIME = ##.##"; CLOCK
'
'***** PREPARE FOR GRAPHING OUTPUT *****
'FILL PLOT ARRAY
'
10 PARR(0, SP) = AD
PARR(1, SP) = AM
PARR(2, SP) = VD
PARR(3, SP) = VACTUAL
PARR(4, SP) = DISTTG
15 '
'
LOCATE 18, 5: PRINT "DISTTG, DIST.ERR = ", INT(DISTTG),
INT(DIST.ERR)
'
20 'SET SCALE FACTORS FOR PLOT
'
FOR I = 0 TO 4
IF ABS(PARR(I, SP)) > SF1(I) THEN
SF1(I) = ABS(PARR(I, SP))
25 END IF
NEXT I
SP = SP + 1
'
'EQUALIZE SCALE FACTORS
30 '
IF SF1(0) > SF1(1) THEN SF1(1) = SF1(0) ELSE SF1(0) =
SF1(1)
IF SF1(2) > SF1(3) THEN SF1(3) = SF1(2) ELSE SF1(2) =
SF1(3)
35 '
'***** PROCESS SIMULATION CONTINUATION AND TERMINATION **
'
IF VACTUAL <= STOPTOLV AND DISTTG <= STOPTOLS AND TSTOP
= 999 THEN
40 TSTOP = CLOCK + 1
FLTTIME = CLOCK
ELSEIF DISTTG <= -76 THEN
GOTO FINISH
FLTTIME = 0
45 END IF
'
'
IF CLOCK < TSTOP THEN
IF BUILD.TABLE% = 1 AND READ.TABLE% = 0 THEN
50 GOTO TIMED.PROFILE
ELSEIF BUILD.TABLE% = 0 AND READ.TABLE% = 0 THEN
GOTO TIMED.PROFILE
ELSE
GOTO PP.PROFILE

```



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```

        END IF
    END IF
    '
    FINISH:
5    '***** STOP SIMULATING AND START GRAPHING *****
    '
    IF LOWLEV% = 1 AND LLTIME% = 0 THEN
        LOCATE 22, 1, 0
        PRINT USING "LOW LEV AT ##.##"; CLOCK
10    LLTIME% = 1
    END IF
    '
    LOCATE 21, 1: PRINT USING "FLIGHT TIME = ##.##"; FLTIME
    LOCATE 24, 1, 1: PRINT "PRESS ANY KEY FOR PLOT...";
15    BEGIN: X$ = INKEY$: IF X$ = "" THEN GOTO BEGIN
    '
    '***** CALL THE GRAPHING SUBROUTINE *****
    '
    'CALL GRAF1(PARR(), GAIN(), SF(), SF1(), XSCALE, XSTART,
20    SCRN, SP, DELTAT)
    END
    '
    SUB LADISTANCE (LADTG, MULTIPLIER, RDISTANCE, distance,
25    VD, DISTTG, DELTATC, LOWLEV%)
    '
    LOCATE 16, 5: PRINT "multiplier= "; MULTIPLIER
    '***** DESCRIPTION *****
    '    LOOK AHEAD DISTANCE TO GO COMPENSATES FOR SOME CONTROL
    '    SYSTEM DELAYS
30    '    IT IS DISABLED FOR THE CONDITIONS INDICATED BELOW
    '    THE MULTIPLIER IS REQUIRED FOR MATCHING OF DISTANCES
    '    PRIOR TO READING OF THE PHASE PLANE TABLE
    '
    35    IF distance > 1000 AND VD > 0 AND LOWLEV% = 0 THEN
        IF DISTTG < RDISTANCE THEN
            RATIO = ABS(DISTTG / RDISTANCE) ^ .25
        ELSE
            RATIO = 1
        40    END IF
        VELDEL = VD * DELTATC * RATIO
    ELSE
        VELDEL = 0
    END IF
45    '
    LADTG = (DISTTG - VELDEL) * MULTIPLIER
    '
    '
    50    END SUB
    '
    SUB STOPD (XSTART, VSTART, AD, XSTOP, VMAX, DECELratio,
    JERK)
    'COMPUTATIONS RELATED TO STOPPING DISTANCE SEQMENT
    '

```



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```

      'The computation is performed in two parts: 1) From
      ' VSTART (jerkout point) to the velocity peak VMAX.
      ' 2) From VMAX back to a speed equal to VSTART.
      ' It can be shown that the time in the second region
5  ' is equal to the time in the first region divided by
      ' the DECELATIO. XSTART is the distance stored away
      ' in the distance table as PPS(PPI%).

      'The equations for velocity and distance given below are
10  ' based on successive integration of jerk to yield
      ' acceleration, velocity, and distance.

      T = -AD / JERK
      T2 = T * T
15  T3 = T2 * T
      VMAX = VSTART + AD * T + JERK * T2 / 2
      X2 = XSTART + VSTART * T + AD * T2 / 2 + JERK * T3 / 6

      JERKDECEL = JERK * DECELATIO ^ 2
      T = T / DECELATIO
      T3 = T ^ 3
      XSTOP = X2 + VMAX * T + JERKDECEL * T3 / 6

25  END SUB

SUB VELCONTROL (VDICT, AM, VM, XM, DT, T, RESETFLAG%,
DRIVELIM) STATIC
      'This is a simple DC direct drive model that includes
30  ' torque limiting (expressed in acceleration units)
      ' and generation of a drive limit signal.
      ' The driven load is assumed to be a pure inertia and a
      ' proportion-integral controller is used.
      ' ***** see last portion of subroutine for model
35  ' description *****
      'VDICT= VELOCITY DICTATION
      'AM= MACHINE ACCELERATION
      'VM= MACHINE VELOCITY
      'XM= MACHINE POSITION
40  'INITIAL CONDITIONS ON INTERNAL STATE VARIABLE EGI=0
      'DT= CYCLE TIME
      'T= ELAPSED TIME
      'TF= TIME CONSTANT OF LAG FILTER THAT PRECEDES VELOCITY
      ' CONTROL
45  'RESETFLAG% >= 1 CAUSES REINITIALIZATION

      '***** INITIALIZE ON FIRST PASS THROUGH *****
      IF RESETFLAG% >= 1 THEN
50          GAIN = 10          'INTEGRAL GAIN
          RESPONSE = 1!      'PROPORTIONAL GAIN/INTEGRAL GAIN
          ALIMPOS = 1400.    ' POS TORQUE LIMIT IN ACCELE-
                              ' RATION UNITS
          ALIMNEG = 1400    ' NEG TORQUE LIMIT IN ACCELE-
                              ' RATION UNITS

```

```

1      LIMFRAC = .8      'FRACTION OF DRIVE LIMITS CAUSING
                           DRIVE LIMIT SIGNAL
      TFILTER = .05      'TIME CONSTANT OF LAG FILTER THAT
                           PRECEDES VELOCITY CONTROL
5      EG1 = 0
      CFILT1 = EXP(-DT / TFILTER)
      CFILT2 = 1 - CFILT1
      GAINRESPONSE = GAIN * RESPONSE
      GAINDT = GAIN * DT
10     RESETFLAG% = 0
      AMOLD = 0
      VMOLD = 0
      ELSE
          GOTO STARTINTEG
15  END IF
      '***** RUN THE INTEGRATION AFTER INITIALIZING *****
      STARTINTEG:
20  VFIL = VFIL * CFILT1 + VDICT * CFILT2
      E1 = VFIL - VM
      EG1 = EG1 + E1 * GAINDT
      EG2 = E1 * GAINRESPONSE + EG1
      E2 = EG2 - VM
25  IF E2 <= LIMFRAC * ALIMPOS AND E2 >= -LIMFRAC * ALIMNEG
      THEN DRIVELIM = 0 ELSE DRIVELIM = 1
      IF E2 <= ALIMPOS AND E2 >= -ALIMNEG THEN AM = E2 ELSE IF
      E2 > ALIMPOS THEN AM = ALIMPOS ELSE AM = -ALIMNEG
      VM = VM + (AM + AMOLD) * (DT / 2)
30  AMOLD = AM
      XM = XM + (VM + VMOLD) * (DT / 2)
      VMOLD = VM
      T = T + DT
      '
35  '***** DESCRIPTION OF MODEL *****
      'BLOCK DESCRIPTION           INPUTS      OUTPUTS
      'INPUT LAG FILTER;TFILTER=TIME CONSTANT VDICT      VFIL
      'SUMMING BLOCK                VFIL,-VM  E1
      'PROPORTIONAL CONTROLLER ;GAIN*RESPONSE E1          EG3
40  'INTEGRAL CONTROLLER ; GAIN*DT      E1          EG1
      'SUMMING BLOCK                EG1,EG3   EG2
      'SUMMING BLOCK                EG2,VM    E2
      'LIMITER ;ALIMPOS & ALIMNEG      E2          AM
      'INTEGRATOR ; TRAPEZOIDAL INTEG.  AM          VM
45  'INTEGRATOR ; TRAPEZIODAL INTEG.   VM          XM
      '
      END SUB

```



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* - * - * - * - *

Although this invention has been shown and described with respect to detailed, exemplary embodiments thereof, it should be understood by those skilled in the art that various changes in form, detail, methodology and/or approach may be made without departing from the spirit and scope of this invention.

Having thus described at least one exemplary embodiment of the invention, that which is new and desired to be secured by Letters Patent is claimed below.



Claims

1. A method of elevator speed dictation control for controlling elevator velocity of an elevator car from zero to a maximum velocity and back to zero in an elevator system based on a velocity profile, comprising:
5 using a velocity profile in which each segment of the velocity profile is generated at one of the limits which constrain the system; viz., at maximum jerk, maximum acceleration, maximum velocity, maximum position or loop gain, or maximum motor torque.
2. The elevator speed dictation control method of Claim 1, wherein there is included the step(s) of:
generating the acceleration portion of the velocity profile in an open loop manner, beginning with
5 constant (maximum) jerk, transitioning to constant (maximum) acceleration after an acceleration limit is attained, and jerking out (negative jerk) at a constant rate to maximum (contract) velocity when the maximum velocity is nearly attained.
3. The elevator speed dictation control method of Claim 1 or 2, wherein there is included the step(s) of:
storing the velocity data in a table as a function of distance gone during acceleration, allowing
5 the table to be used in reverse to find dictation as a function of distance to go during deceleration.





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4. The elevator speed dictation control method of Claim 3, wherein there is included the step(s) of:
building the velocity table from acceleration and jerk constraints so that the acceleration corresponding to each velocity is known and storing the
5 acceleration information along with the velocity information in tables having distance as the independent variable.

5. The elevator speed dictation control method of Claim 3 or 4, wherein there is included the step(s) of:
making the table entries during each processor cycle during acceleration.

6. The elevator speed dictation control method of any one of claims 3 to 5, wherein there is included the step(s) of:
using the acceleration table in reverse together with a numerical scaling to decelerate the
5 elevator.

7. The elevator speed dictation control method of any one of claims 1 to 6, wherein there is further included the step(s) of:
outputting the acceleration information by
5 the profile generator at all times, including acceleration, constant speed, deceleration.

8. The elevator speed dictation control method of any one of claims 1 to 7, wherein there is included the step(s) of:
finding acceleration without any numerical differentiation of velocity.



* C L M S *



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9. The elevator speed dictation control method of any one of claims 1 to 8, wherein there is included the step(s) of:

blending the acceleration signal with the velocity signal and applying the combination as a dictation to a drive for the elevator car, providing an "acceleration feedforward" that reduces velocity tracking time, making the drive more responsive.

10. The elevator speed dictation control method of any one of claims 1 to 9, wherein there is included the step(s) of:

providing a proportional-integral controller used in the drive for the elevator car; and

compensating for load sensitivity by varying the proportional gain of the proportional-integral controller as a function of load weight.

11. The elevator speed dictation control method of any one of claims 1 to 10, wherein there is included the step(s) of:

using an algorithm for computing stopping distance, in which the stopping distance is computed based on the DICTATED profile and comparing stopping distance to DISTTG (distance to go; DRIVE OUTPUT COORDINATES) converted to DICTATION coordinates.

12. The elevator speed dictation control method of Claim 11, wherein there is included the step(s) of:

measuring the distance tracking error by numerically integrating the dictated velocity to find the distance dictated; and

accomplishing the conversion of DISTTG to DICTATION coordinates by subtracting tracking distance error from DISTTG in which the

$\text{DISTANCE GONE} = \text{LENGTH OF RUN} - \text{DISTTG}$, and

$\text{DISTANCE DICTATED} - \text{DISTANCE GONE} = \text{DISTANCE TRACKING ERROR}$.

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* C L M S *

13. The elevator speed dictation control method of Claim 12, wherein there is included the step(s) of:
issuing a stop control command (SCC) when the following condition is true -

5 STOPPING DIST. ≥ DISTTG - DIST. ERROR -
 (N * VEL * DELTAT)

wherein STOPPING DIST. is computed; DISTTG comes from a position transducer; DIST. ERROR is also measured; and N accounts for a number of cycles of the order of about two (2) of delay in the processor system, VEL is dictated velocity and DELTAT is the processor cycle time.

14. The elevator speed dictation control method of any one of claims 1 to 13, wherein there is included the step(s) of:

- decelerating the elevator with look-ahead-distance-to-go (LADTG) as the independent variable; and
- using a multiplier in the profile generator as a scaling factor that acts on the LADTG to make it equal to the distance range for the velocity and acceleration tables.

15. The elevator speed dictation control method of Claim 14, wherein there is included the step(s) of:
making the look-ahead-distance-to-go (LADTG) adaptive and, as the end of a run is approached, using a "washout" term for LADTG which is a function of DISTTG;
and

as DISTTG approaches zero, using a multiplier to act on the velocity dependent portion of LADTG to make that term less and less significant.





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16. The elevator speed dictation control method of Claim 15, wherein there is included the step(s) of:
reverting phase plane control to pure DISTTG, should the control overshoot and the DISTTG go
5 negative, and discontinuing use of LADTG as the independent variable.

17. The elevator speed dictation control method of any one of claims 1 to 16, wherein there is included the step(s) of:
making the profile generator adaptive by presetting the acceleration and jerk limits based on the
5 load in the elevator cab by a computation based on load weight made at the beginning of a run.

18. The elevator speed dictation control method of any one of claims 1 to 17, wherein there is included the step(s) of:
reducing acceleration at a speed close to the base speed of the motor, keeping power requirements
5 well bounded without significantly compromising flight time, as a form of acceleration profile adaptation based on speed.



* C L M S *



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Abstract

ELEVATOR SPEED DICTATION SYSTEM

An elevator speed dictation system for controlling the elevator velocity from zero to a maximum velocity and back to zero, illustrated in functional block form in Fig. 1. Velocity profiles over eight regions (Regions 0-7) are provided for zero speed (0), low level phase plane (1), constant jerk to prescribed acceleration (2), prescribed acceleration (3), constant jerk down to constant velocity (4), jerk level after generation of Stop Control Command (SCC; 5), constant speed (6), and phase plane (7), respectively. Velocity profiles for Regions 0-7, including traces of velocity (10), velocity dictated (20), acceleration (30), dictated acceleration (40) and distance to go (50) versus time are graphically illustrated in Fig. 2 & Figs. 4-6 for a long elevator car run, Intermediate II (transition to Region 5 occurs after SSC), Intermediate I (transition occurs from Regions 3 to 5), and a short elevator car run, respectively; while Fig. 7 illustrate velocity and acceleration curves used to find the stopping distance. Fig. 3 provides a flow chart for the transitions between the various regions (0-7) of the profiles.

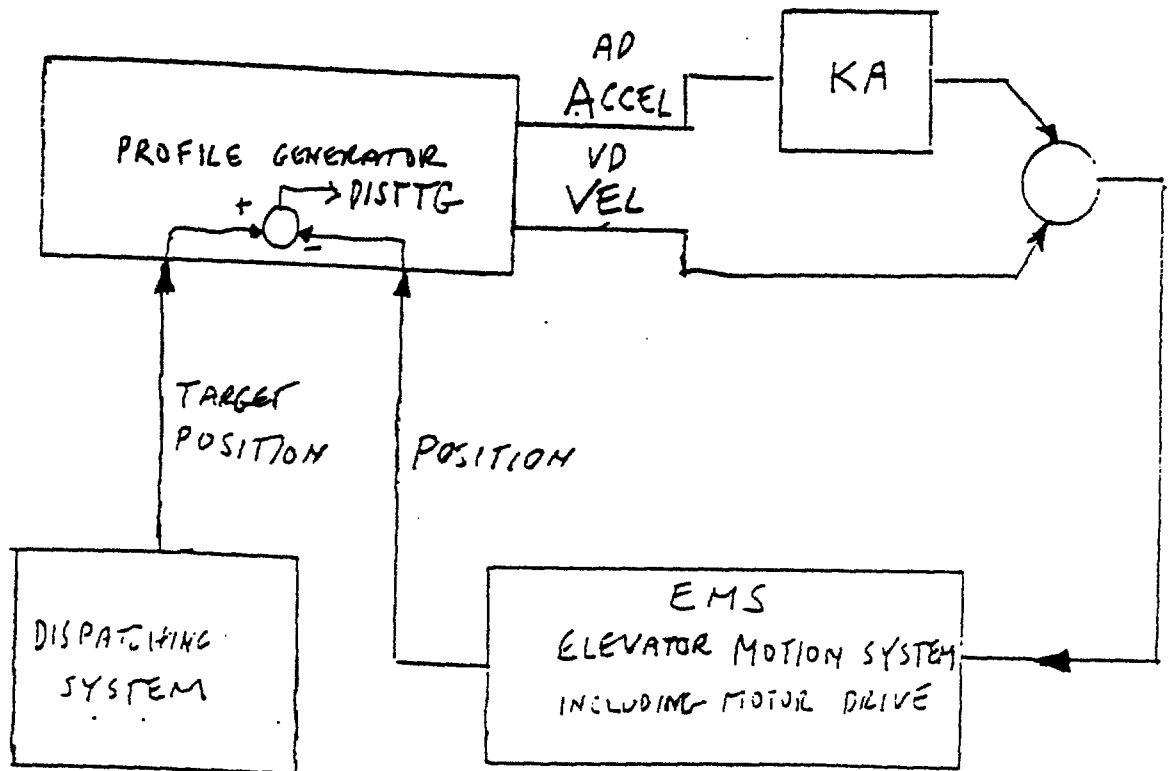
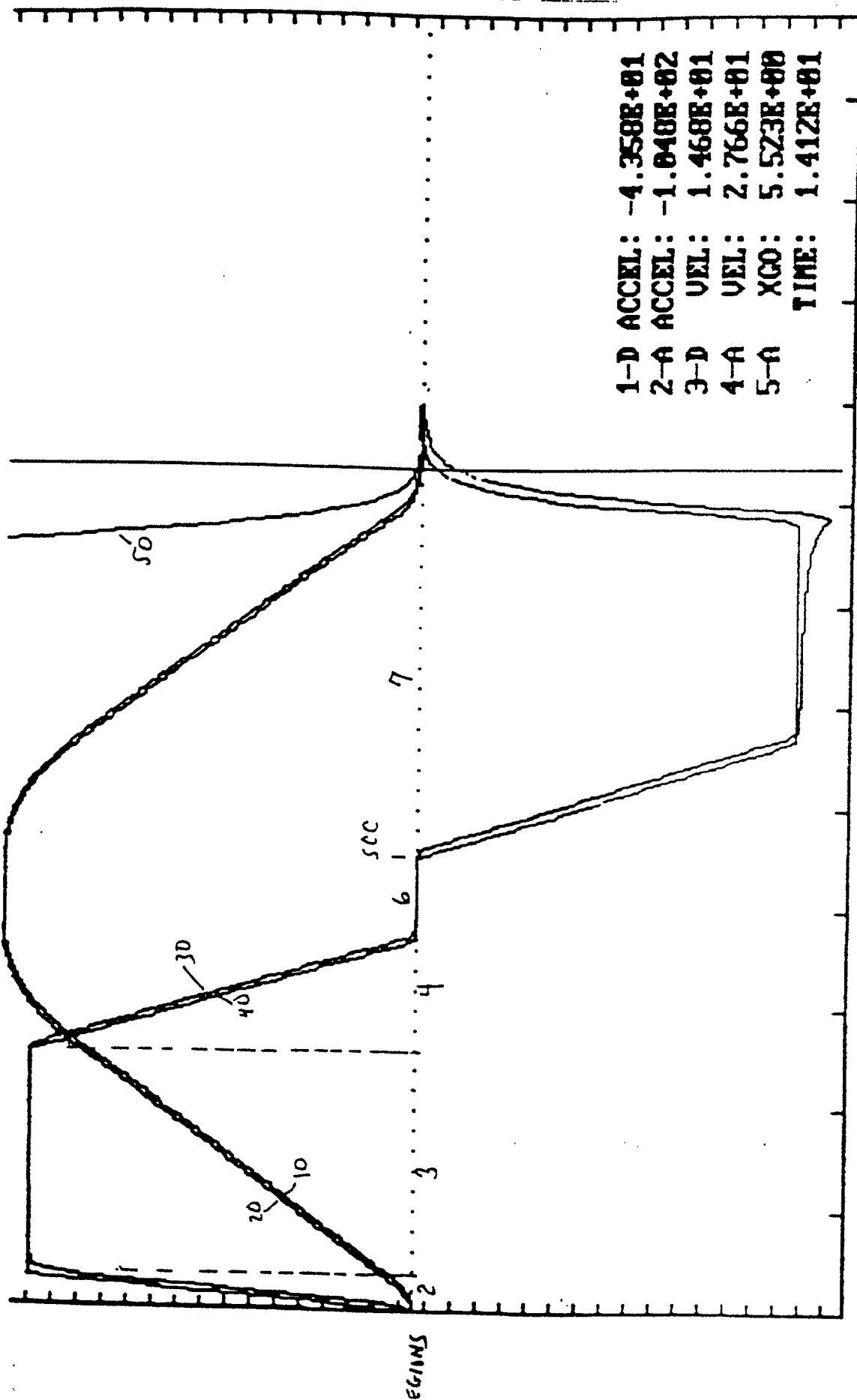
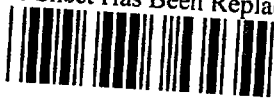


FIGURE 1





TIME

FIGURE 2

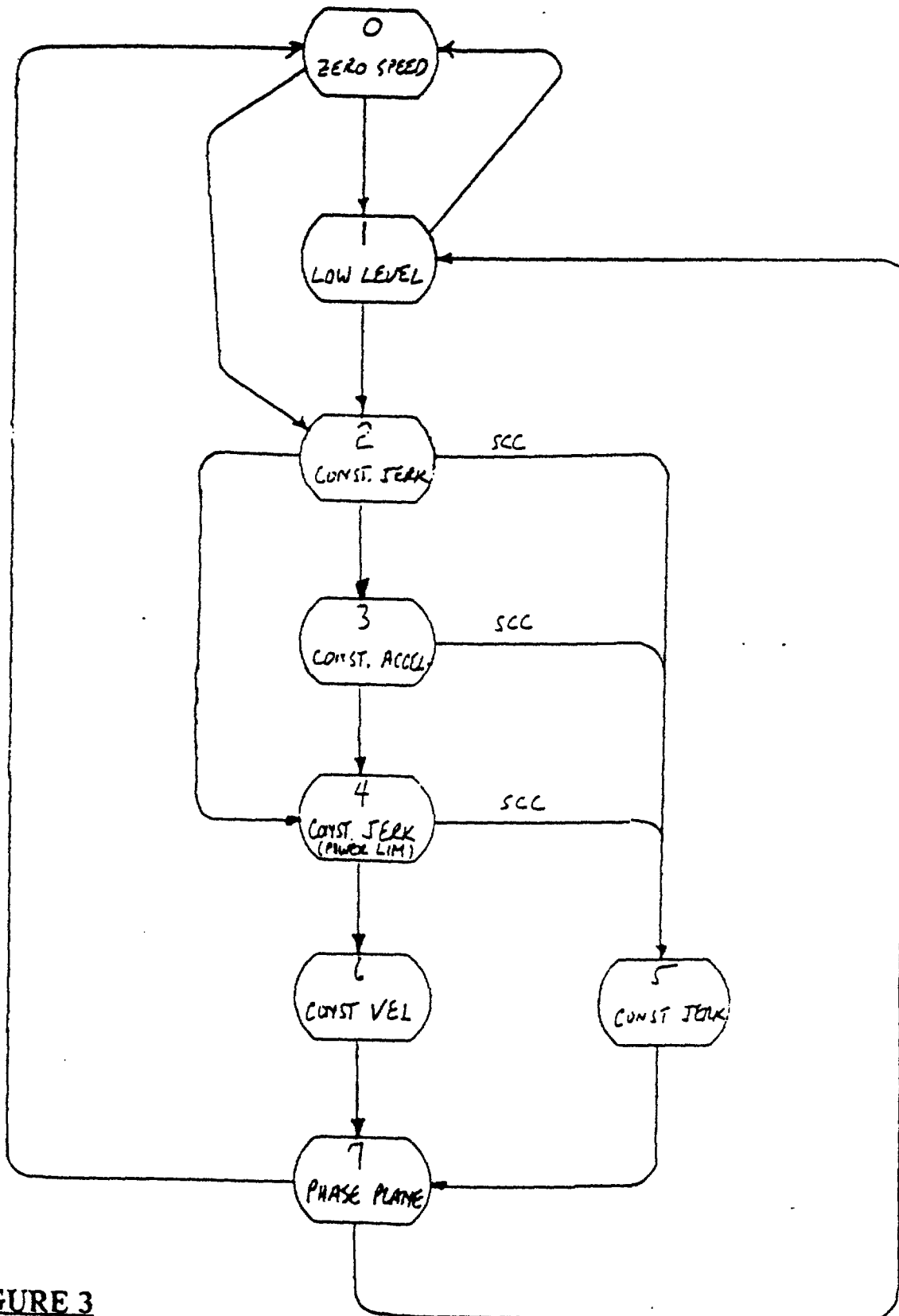


FIGURE 3

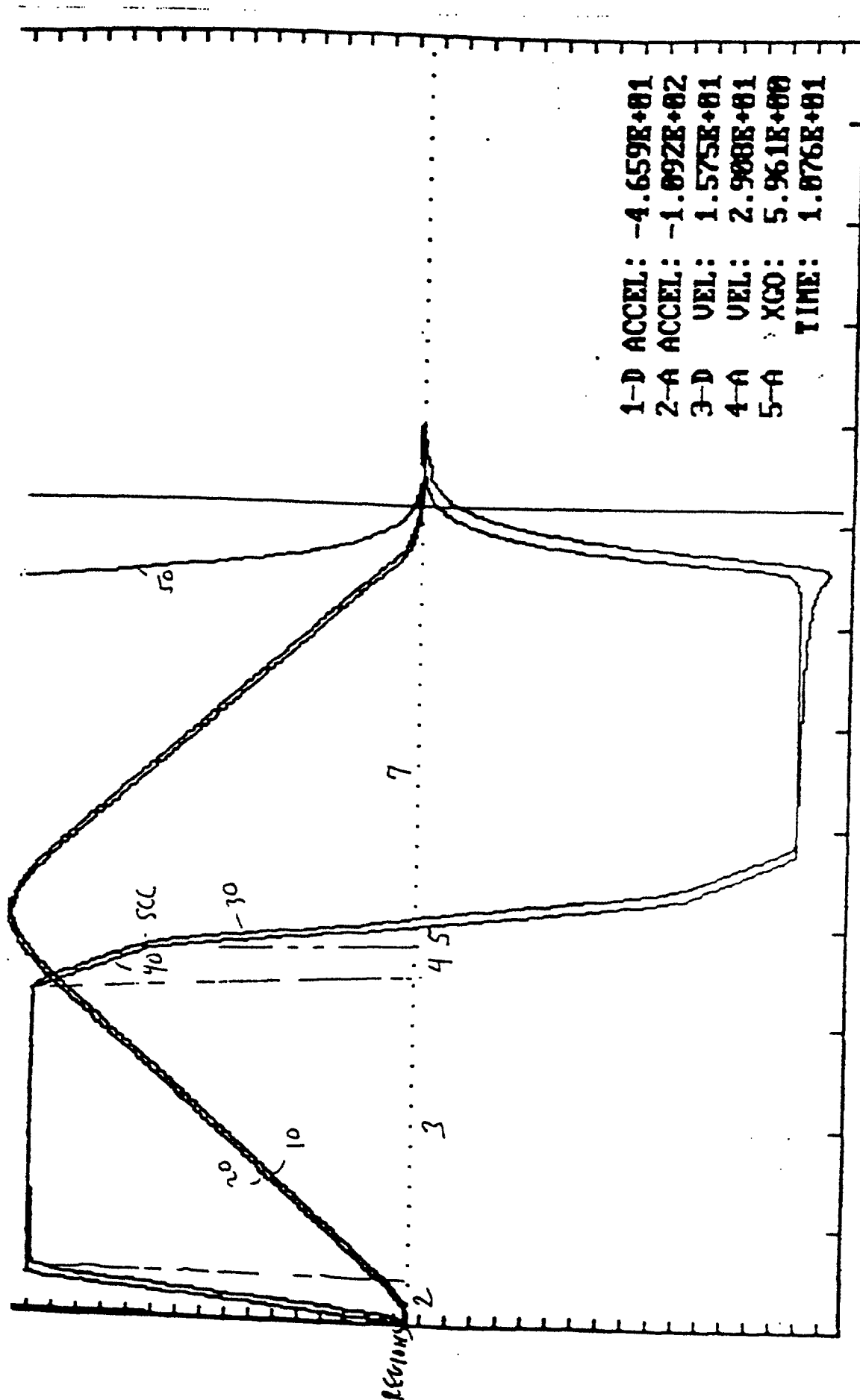


FIGURE 4

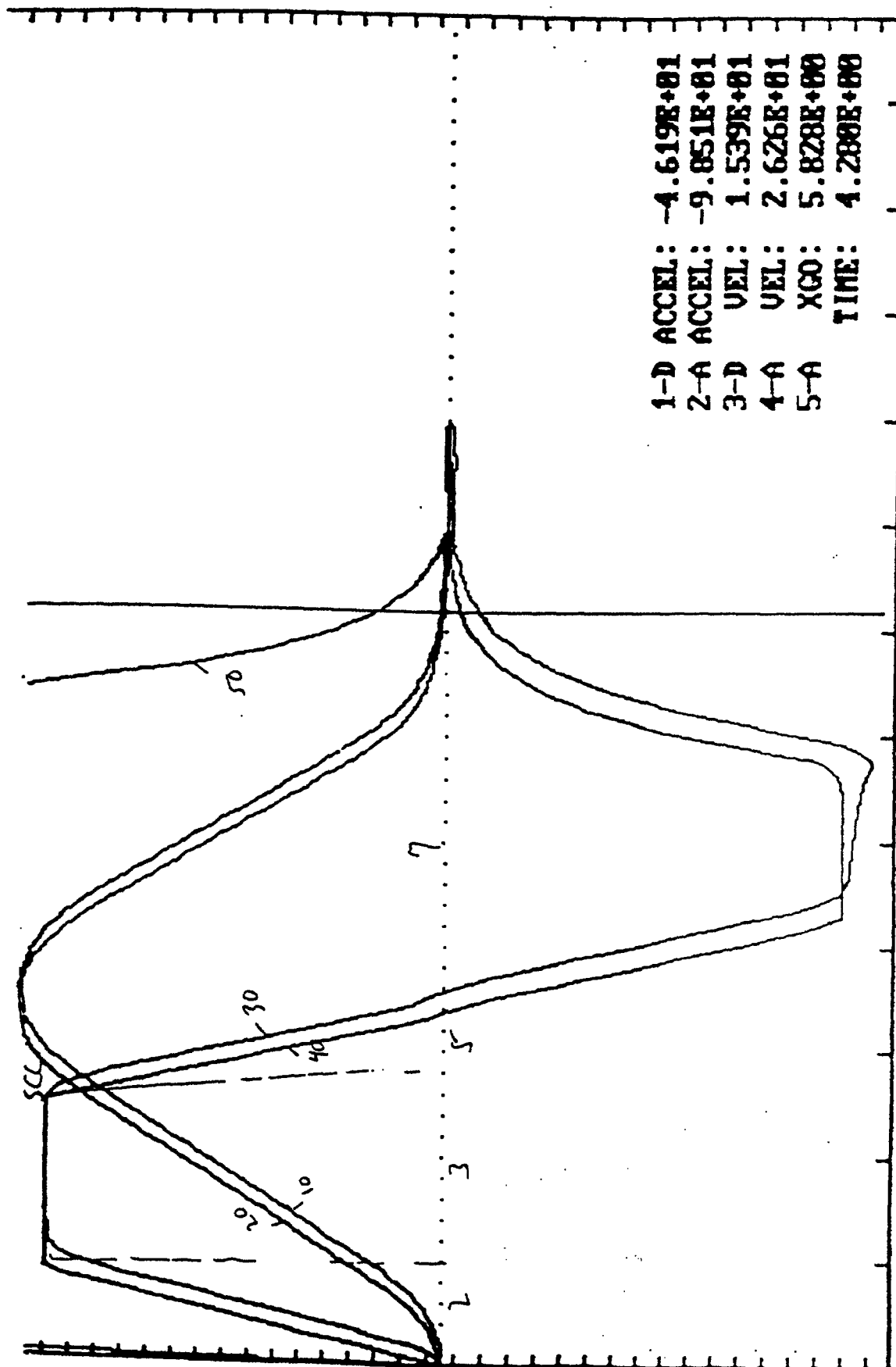


FIGURE 5

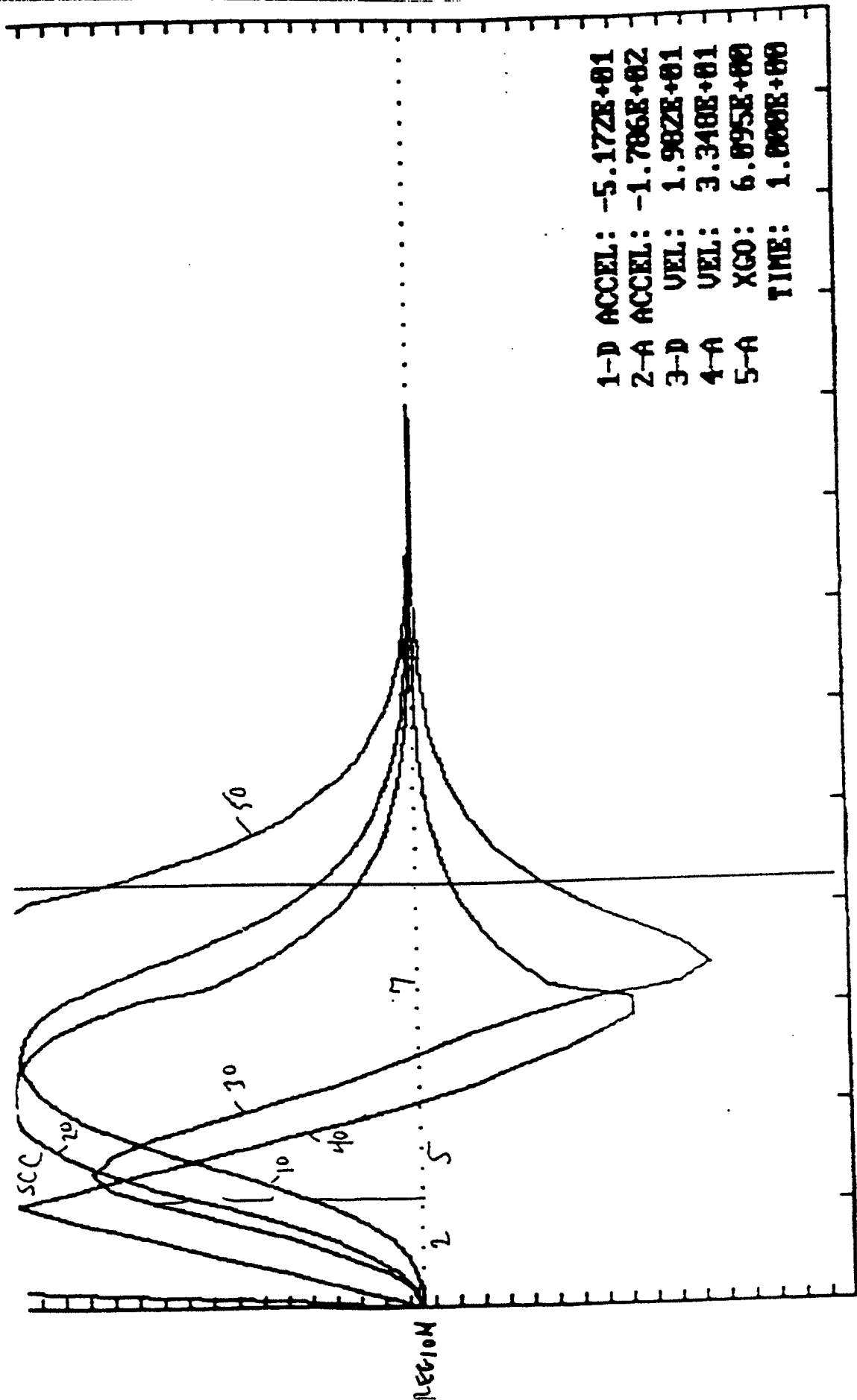


FIGURE 6

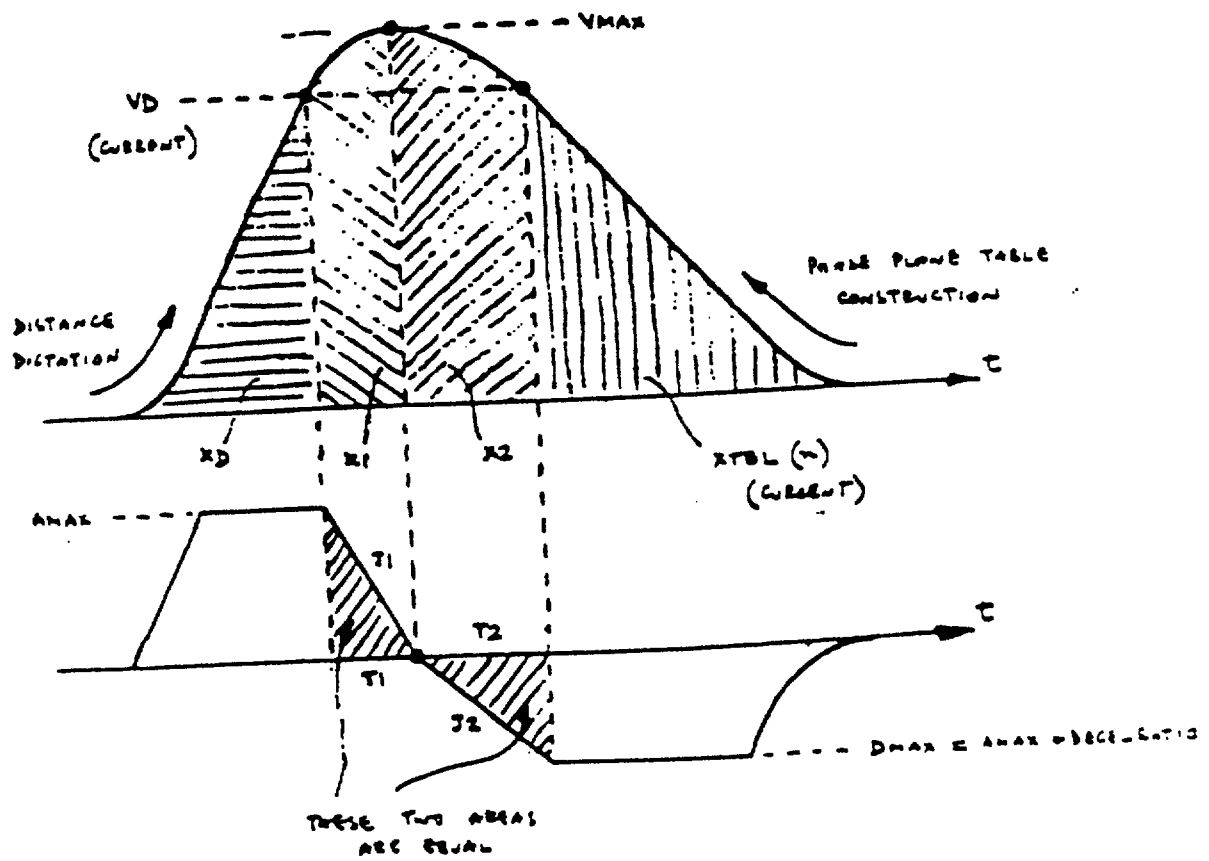
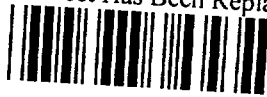


FIGURE 7



REPLACED SHEETS	
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✓ Description : paged 1 to paged 32	32
✓ Claim(s) : paged 33 to paged 37	37
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✓ Abstract : paged 37 to paged 37	-

Description

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ELEVATOR SPEED DICTATION SYSTEM

Technical Field

The present invention relates to elevator systems and in particular to elevator velocity control.

Background Art

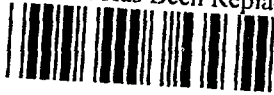
The need to control the velocity of an elevator is well known. Reference is had, for example, to assignee's U.S. Patent 4,751,984 of Walter L. Williams, Donald G. McPherson & Arnold Mendelsohn entitled "Dynamically Generated Adaptive Elevator Velocity Profile" issued June 21, 1988, as well as to the art cited therein.

As noted in the Williams et al. patent, automatic elevator operation requires the control of elevator velocity with respect to zero or stop, at the beginning and the end of a trip, to speeds therebetween, which minimize trip time while maintaining comfort levels and other constraints. The time change in velocity for a complete trip is termed a "velocity profile." Automatic elevator control further requires control of the distance travelled during a trip in order to accomplish a precision stop at the destination floor.

Certain velocity profile generation strategies may lead to control instabilities. A common strategy is to use a phase-plane control for precision stopping, wherein dictated velocity is a function of the distance to go to the landing. As the distance-to-go approaches zero, the slope of the velocity/distance curve approaches infinity (∞). Using linear control theory, it can be shown that the slope of the phase-plane curve represents the position error gain for phase-plane control and is proportional to position loop bandwidth. For the speed

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control loop to track the dictated velocity profile with stability, its bandwidth must be greater by a significant factor than the bandwidth of the position control loop.

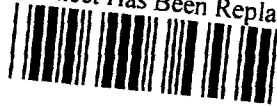
One strategy for reducing the required bandwidth is to limit the slope of the phase-plane velocity versus position profile (position error gain) to a maximum value, such that the position loop bandwidth is sufficiently lower than the velocity loop bandwidth.

Generally, the torque producing capability of elevator motors may vary with speed due to motor current, voltage, and/or power limitations. If the drive is not capable of maintaining the acceleration limit under all conditions due to these torque limits, some means of reducing the acceleration (and hence torque) in the corresponding portions of the velocity profile must be provided without compromising operation of the drive at its limit or complicating the profile generation more than necessary.

To avoid, inter alia, these problems, in Williams et al. each segment of the velocity profile was generated at one of the limits constraining the system; viz., at maximum jerk, maximum acceleration, maximum velocity, maximum position or loop gain, or maximum motor torque. The acceleration portion of the velocity profile preferably was generated in an open loop manner, beginning with constant (maximum) jerk, transitioning to constant (maximum) acceleration after an acceleration limit is attained, and jerking out (negative jerk) at a constant rate to maximum (contract) velocity when the maximum velocity is nearly attained. However, although Williams et al. represented a very substantial advance in the art, it also was subject to improvement, to which the present invention is directed. The disclosure of the Williams et al. patent is incorporated herein by reference.

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Disclosure of Invention

In the invention, at a speed close to the base speed of the motor, acceleration reduction preferably is used to keep power requirements well bounded without significantly compromising flight time. This is a form of acceleration profile adaptation based on speed.

Another type of adaptation also may be used. The acceleration and jerk limits for the profile may be adjusted in accordance with available torque. The torque requirements may be determined from the load weighing signal, which gives the load in the cab. The acceleration and jerk limits for the profile can then be adjusted accordingly.

Thus, the profile generator can be made adaptive by presetting the acceleration and jerk limits based on the load in the elevator cab. This can be done by a simple computation based on the load weight made at the beginning of a run. This could be done to permit the use of a smaller than usual drive system, if so desired.

The dictation system of the present invention is capable of generating for output high-quality velocity and acceleration signals. It is advantageous because it is highly structured in design, tolerant of significant computational errors, and is easily modified to handle unusual situations.

Therefore, it is an object of the present invention to produce a minimum-time velocity/acceleration profile, subject to the following constraints:

- contract speed(s) (as in Williams et al.);
- ride comfort constraints; i.e., acceleration and jerk limits (as in Williams et al.);
- drive torque and power limits (following to some degree Williams et al.); and
- compatibility with the drive system.

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In addition, like Williams et al., the velocity-profile generation approach of the present invention preferably:

- provides for precision stopping at the destination floor and re-leveling;

- complies with the code required door zone and other terminal landing speed limits; and

- accommodates short runs where the contract speed is not reached, as well as very short runs where the "stop control command" (SCC) is reached before the velocity "VBASE" (described more fully below) is reached.

According to the invention and as part of the improvement to the approach of Williams et al., each segment of the velocity profile likewise is generated at one of the limits which constrain the system; viz., at maximum jerk, maximum acceleration, maximum velocity, maximum position or loop gain, or maximum motor torque. The acceleration portion of the velocity profile preferably is generated in an open loop manner, beginning with constant (maximum) jerk, transitioning to constant (maximum) acceleration after an acceleration limit is attained, and jerking out (negative jerk) at a constant rate to maximum (contract) velocity when the maximum velocity is nearly attained.

The invention may be practiced in a wide variety of elevator applications utilizing known technology, in the light of the teachings of the invention, which are discussed in detail hereafter.

Some of the technological advances achieved and/or followed in the preferred embodiment of the present invention are outlined below.

1. The velocity is stored in a table as a function of distance gone during acceleration. This table can be used in reverse to find dictation as a
35 function of distance to go during deceleration. The new profile generator explicitly builds the velocity table

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from acceleration and jerk constraints. This means that acceleration corresponding to each velocity is known. The new profile generator stores acceleration information along with velocity information in tables having distance as the independent variable. Table entries are made during each processor cycle during acceleration. The acceleration table is used in reverse together with a numerical scaling to decelerate the elevator. Acceleration information is output by the profile generator at all times (acceleration, constant speed, deceleration). No numerical differentiation of velocity is used to find acceleration, except in special situations. This results in a high-quality acceleration signal. Also, processor time is saved.

2. The acceleration signal mentioned in "1" above can be blended with the velocity signal and the combination applied as dictation to a drive. This provides an "acceleration feedforward" that reduces velocity tracking time and thus makes the drive more responsive. The acceleration signal can also be applied in standard fashion to the torque input point of a drive (if available). A disadvantage of feedforward is that it makes the drive system more load sensitive. Load sensitivity can be compensated for, if a load weight signal is available. This may be accomplished by varying the proportional gain of the proportional-integral controller used in the drive as a function of load weight.

3. The new profile generator has a simple algorithm for computing stopping distance. The algorithm can be used for runs of all lengths. The stopping distance is computed based on the DICTATED profile.

4. The stopping distance in "3" is compared to DISTTG (distance to go; DRIVE OUTPUT COORDINATES) converted to DICTATION coordinates. The conversion is
35 accomplished by subtracting the tracking distance error

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from DISTTG. In the new profile generator the distance error is not entered in terms of drive tracking delay and velocity. Instead, the actual, MEASURED, distance tracking error is used. The measurement is accomplished by using numerical integration of dictated velocity to find distance dictated. The

DISTANCE GONE = LENGTH OF RUN - DISTTG, and
DISTANCE DICTATED - DISTANCE GONE = DISTANCE
TRACKING ERROR.

The stop control command (SCC) is issued when the following condition is true:

STOPPING DIST. $\geq$ DISTTG - DIST. ERROR -
(2 * VEL * DELTAT)

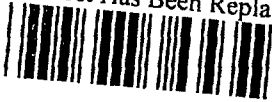
STOPPING DIST. is computed; DISTTG (distance to go) comes from a position transducer; DIST. ERROR is also measured; and the last term accounts for two cycles of delay in the processor system. VEL is dictated velocity and DELTAT is the processor cycle time (10-40 ms is typical).

5. The stop control command as defined in "4" usually cannot be issued perfectly. The distance range applicable to the velocity and acceleration tables will not match the distance to go. This problem becomes especially severe when the elevator is to be decelerated with look-ahead-distance-to-go (LADTG) rather than DISTTG as the independent variable. The problem is solved in the new profile generator by the introduction of a MULTIPLIER. This multiplier is a scaling factor that acts on the LADTG to make it equal to the distance range for the velocity and acceleration tables. Usually the MULTIPLIER is a number very close to one (1.0) for long runs. It may deviate significantly from one (1.0) for very short runs because of numerical errors. The MULTIPLIER assures that numerical errors, timing delays, etc., will not cause bizarre phase plane trajectories.

35 The phase plane-control in the profile generator of the

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invention is self-correcting and robust because of the MULTIPLIER.

6. The look-ahead-distance-to-go (LADTG) is made adaptive in the new profile generator. It is not used for runs of less than 1000 mm (pure DISTTG is used). Further, as the end of a run is approached, LADTG has a "washout" term which is a function of DISTTG. As DISTTG approaches zero, a multiplier acts on the velocity dependent portion of LADTG to make that term less and less significant. Should the control overshoot and the DISTTG go negative, phase plane control reverts to pure DISTTG, rather than LADTG as the independent variable.

7. The profile design is modular, structured, and deterministic. Acceleration, jerk, and distance constraints permitting, it is capable of being altered after a run has begun. The modular design makes design modifications relatively easy. Maintenance of the code and teaching of the design to new engineers is not complicated.

8. The profile generator can be made adaptive by presetting the acceleration and jerk limits based on the load in the elevator cab. This is done by a simple computation based on load weight made at the beginning of a run. This could be done to permit use of a smaller than usual drive system. Working of examples indicates that significant cost savings are possible with little degradation in overall service (traffic flow).

Other features and advantages will be apparent from the specification and claims and from the accompanying drawings, which illustrate two exemplary embodiments of the invention.

Brief Description of Drawings

Figure 1 is a simplified, block diagram of an exemplary embodiment of the elevator speed dictation system of the present invention.

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Figure 2 is a graph of the velocity profile of the invention for an exemplary long run of an elevator car in accordance with the exemplary principles of the present invention. (It is noted that the numerical information on the lower, right side of the figure refers to the data values of the traces at the vertical cursor line located to the left side of the graphed, displayed traces; the same being true of Figs. 3-6.)

Figure 3 is a flow chart showing the transitions between the regions of the velocity profile of Figure 2, as well as of the velocity profiles of Figures 4-6, with Regions 0 (zero speed) and 1 (low level phase plane) not being illustrated for simplicity purposes in the velocity profiles.

Figure 4 is a graph of the velocity profile of the invention for an exemplary "Intermediate II" profile of the elevator car, in which the Intermediate II profile illustrates the situation wherein a transition to Region 5 occurs after a Stop Control Command (SCC).

Figure 5 is a graph of the velocity profile of the invention for an exemplary "Intermediate I" profile of the elevator car, in which the Intermediate I profile illustrates the situation wherein there is a transition from Region 3 to Region 5.

Figure 6 is a graph of the velocity profile of the invention for an exemplary short run of the elevator car.

Figure 7 is a comparative graph of exemplary velocity and acceleration curves used in the invention to find the stopping distance.

Best Modes for Carrying Out the Invention

As noted in Williams et al., in order to provide rapid, controlled and smooth motion control in an elevator, a velocity profile is generated which observes
35 constraints regarding jerk, acceleration and equipment

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limitations. Typical, exemplary requirements for a high performance system are:

RISE	-	up to 400 M
LOADS	-	900 TO 3600 KG
SPEEDS	-	2.5 to 10 M/S
ACCEL.	-	up to 1.5 M/S
JERK	-	up to 3.0 M/S
LEVELING	-	± 0.006 M

An exemplary function block diagram of the invention is shown in Figure 1. The profile generator (PROFILE GEN.) delivers a velocity signal "VD" and an acceleration signal "AD" to an elevator control system. The gain "KA" is used to control the blend of the acceleration signal to the velocity signal in a feed-forward control. Alternatively, the acceleration signal may be routed directly to the motor torque control point in the motor drive.

Sometimes limiters or filters (not illustrated) are used between the VD and AD signals and the elevator motion system ("EMS"). The EMS includes a position reference system, which feeds back the car position ("POSITION") to the profile generator.

The function of the profile generator is to bring the car to the target position within the acceleration and jerk constraints. These constraints may be fixed or they may be a function of available power, motor torque, etc. Just before and sometimes even during a run, the constraints may be changed. The profile generator is designed in a structured fashion, thereby permitting adaptation to changing circumstances, even when a run is under way.

The overall position control system should bring the car to its destination in a minimum amount of time, without vibrations or overshoot. The overall positioning
35 accuracy sought is usually better than plus-or-minus

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three millimeters (± 3 mm), although plus-or-minus six millimeters (± 6 mm) is acceptable.

The acceleration limit is usually set by the available torque in the motor drive. However, in an oversized system, passenger comfort may determine the acceleration limit.

In many systems the passenger comfort acceleration sets the acceleration with the motor torque limitation becoming a problem, only when the cab is empty or fully loaded. Most high-performance elevator systems are equipped with a load-weighing system.

Knowledge of elevator system parameters and the load weight permits computation of the maximum allowed acceleration based on the motor torque limit. Those skilled in the elevator art may routinely make this calculation, which is based on the mass of the hoistway equipment, the overbalance used for the counterweight, the load in the cab, and the available motor torque.

Part of the torque is used to offset unbalance and friction forces. The other part is used to accelerate or decelerate the system mass.

The profile construction strategy of the invention will now be described first in terms of typical profiles produced by the exemplary apparatus of the invention.

Figure 2 shows the dictated and actual velocity and acceleration for an exemplary long run. Understanding this profile set is important because all other profile sets are subsets of this one. As can be seen in Figure 2 various regions 2-7, defined and explained more fully below, are marked.

The profiles for the first part of the run are developed on the basis of dictated acceleration. Dictated velocity is obtained by the numerical integration of the dictated acceleration. (Henceforth, as a matter of form and for simplicity purposes, dictated

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velocity and acceleration typically will be referred to without the adjective "dictated" being added.) The actual position, velocity, and acceleration are outputs from the EMS.

It is noted that the quantity target position - position = distance-to-go ("DISTTG"). A greatly amplified trace of "DISTTG" 50 is shown in Figure 2.

The regions in Figure 2 are defined as follows and illustrated in block form in Figure 3:

<u>Region</u>	<u>Definition</u>
0	zero speed
1	low level phase plane
2	constant jerk to prescribed acceleration
3	prescribed acceleration
4	constant jerk down to constant velocity
5	jerk level after generation of SCC
6	constant speed
7	phase plane

Regions "0," "1," and "7" apply to runs of all lengths. Regions 0 and 1 are not shown explicitly on the profiles illustrated in Figures 2, etc., and the meaning of Region 1 is explained when the phase-plane Region 7 is explained.

In the profiles of Figure 2 and Figures 4-6, the profile traces and the parameters they represent are tabulated below:

<u>Trace #</u>	<u>Parameter</u>
10	velocity
20	velocity dictation
30	acceleration
40	dictated acceleration
50	distance to go (greatly magnified)

Figure 2 will now be discussed on a time-history basis. The elevator car is stopped. It then accelerates at "constant jerk" in Region 2 until the acceleration limit is reached.

The end of Region 3 is defined when "VBASE" is reached. "VBASE" can be the base velocity or speed of the motor or a lower speed. "VBASE" is subject to some

variation, and, typically, it will be close to but a bit less than the base speed of the motor involved. A "jerk out" is then defined in Region 4 until maximum speed is reached in Region 6. Operation continues in Region 6, until the stop control command (SCC) is received.

Region 7 is then entered. In that region the velocity is commanded as a function of distance-to-go on the basis of a table of velocity versus distance built up for all travel in Regions 2-5. At the time the velocity table is being built, an acceleration table is also being built. Both the velocity and acceleration tables can be weighted, so that deceleration occurs in direct proportion to a set "DECELRTIO." The "DECELRTIO" is usually less than one (<1.0), but it may also be larger than one (>1.0).

The profile generator regions are illustrated in block form in Figure 3. The transitions from Regions 1 to 0 and 0 to 1 are used at the beginning of a run for holding the elevator at the floor when the brake is lifted and the transition to Region 2 is about to commence. Upon receipt of SCC, it is possible to leave Regions 2-4 and enter Region 5.

Deceleration of the elevator occurs in Region 7 using a phase-plane control. The dictated velocity and acceleration used are retrieved from tables built in Regions 2-5. When the elevator has almost landed or during recovery from an overshoot, the low-level phase plane Region 1 is entered. The low-level-phase plane has a linear slope (velocity/DISTTG) in a range of, for example, one to four ($1-4 \text{ sec}^{-1}$) 1/second.

Actual operation for less than full-length runs is illustrated in Figures 4-6. Figure 4 is termed "Intermediate II" because the transition to Region 5 occurs after SCC. Figure 5 is an "Intermediate I" profile because a transition occurs from Region 3 to Region 5. This figure illustrates the typical operation

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for a one-floor run. Figure 6 is a short run in which the acceleration limit, Region 3, is not reached, and, thus, transition occurs directly from Region 2 to Region 5.

Proper operation of the profile generator system requires careful attention to detail, especially if smooth, error tolerant operation is desired. These details are described below.

- Major Operations in Profile Generation -

The timed portions of the profiles are obtained by successive numerical integrations using the trapezoidal algorithm. This has the following general form:

$$X_n = X_{n-1} + (T/2)(dX_n/dt + dX_{n-1}/dt)$$

where -

X_{n-1} is the previous value of X_n
(computed at time $t_{n-1} = t_n - T$); and

T is the step size (cycle time, sampling rate).

The major operations other than generation of a timed profile are listed here. Those occurring in Regions 2-6 are:

1. Build the linear portion of the phase-plane table.
2. Build the phase-plane table in regions 2-5.
3. Compute the stopping distance (Regions 2, 3, 4, 6).
4. Determine the distance error and SCC.

The following operations are important in transitioning to, and operating in, Region 7 (phase plane):

1. Determine the "MULTIPLIER" for coordinate transformation.
2. Compute the Look-Ahead-Distance-To-Go ("LADTG") from DISTTG.
3. Interpolate the velocity and acceleration tables.

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4. Transition to low-level phase plane at the end of the run.

Details of the foregoing operations are discussed below.

- Phase Plane Table Building -

The phase plane table is built dynamically in a microprocessor during the timed acceleration portion of the profile. As the acceleration and velocity dictation signals are computed each cycle, they are stored in a table together with the index and a corresponding distance. The table is built to satisfy the profile requirements in the phase plane deceleration region. At low speeds where $VD \leq LEVELVEL$ (elevator approaches the destination), the relationship between the dictated velocity and the distance-to-go is linear -

$$VD = K * DISTTG$$

The corresponding dictated acceleration is calculated as -

$$AD = K * VD$$

where K is the position loop gain (see Fig. 1). For standard profiles -

$$K = LEVELGAIN$$

For speeds where $VD > LEVELVEL$, the relationship between VD and DISTTG is nonlinear. The acceleration, velocity, and position entries in the table are obtained by successive integrations, and the table index is incremented each cycle.

Taking the DECELRTIO factor into account, the equations used for table building are:

$$\text{If } VD_n \leq LEVELVEL$$

then -

$$INDEX = n$$

$$VTBL(n) = VD_n$$

$$XTBL(n) = VD_n \div K$$

$$ATBL(n) = VD_n * K$$

However -

```

      if    VDn > LEVELVEL
    then -
      INDEX    = n
      VTBL(n)  = VDn
      ATBL(n)  = ½ * [ATBL(n-1) + ADn * DECELRTIO]
      XTBL(n)  = XTBL(n-1) +
                  + ½T * [VTBL(n-1) + VDn] ÷
                  DECELRTIO
  
```

where -

$$\text{LEVELVEL} = \text{AD}_n * \text{DECELRTIO} \div K$$

Table building continues until the acceleration reaches zero, or, in other words, it is stopped for one of two reasons:

- (1) Region 7 (phase-plane) is entered without going through Region 6 (constant velocity); or
- (2) a transition is made to Region 6.

- Stopping Distance and SCC Determination -

Besides table building, computations preferably are being made during acceleration to determine the stopping distance based on the dictation. This stopping distance is correct if no time delays exist in the velocity control system.

The following basic equations applied to Figure 7 are used to compute the stopping distance when Region 6 (constant velocity) is not entered:

$$\text{JD}_n = \text{J}_0$$

$$\text{AD}_n = \text{A}_0 + \text{J}_0 * t$$

$$\text{VD}_n = \text{V}_0 + \text{A}_0 * t + \frac{1}{2} * \text{J}_0 * t^2$$

$$\text{XD}_n = \text{X}_0 + \text{V}_0 * t + \frac{1}{2} * \text{A}_0 * t^2 + \frac{1}{6} * \text{J}_0 * t^3$$

where -

JD_n, AD_n, VD_n and XD_n are the current dictated, jerk, acceleration, velocity and distance, respectively (at time t = t_n); and J₀, A₀, V₀ and X₀ are the initial
 35 jerk, acceleration, velocity and distance, respectively.

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If the SCC command is generated during the constant velocity portion (Region 6), then the stopping distance is determined only by the current distance stored in the table. Otherwise, the stopping distance is given, after some derivation, by:

$$\begin{aligned} \text{STOP.DIST} = & \text{XTBL}(n) + \\ & + (\text{VD}_n * \text{AD}_n / J_0 + 1/3 * \text{AD}_n^3 / J_0^2) * (1 + \\ & + 1/\text{DECEL RATIO}) \end{aligned}$$

The stopping distance must be compared not to the actual distance-to-go but to that value corrected for delays. The following equality defines the stop control command (SCC) point, when processor system delays are neglected.

$$\text{STOP.DIST} = \text{DISTTG} - \text{DIST.ERR.}$$

where -

$$\text{DISTTG} = \text{TARGET.POS} - \text{CURRENT.POS}$$

$$\text{DIST.ERR} = \text{DIST.DICT} - \text{DIST.GONE}$$

$$\text{DIST.GONE} = \text{CURRENT.POS} - \text{STARTING.POS}$$

The dictated distance "DIST.DICT" is computed by integrating the dictated velocity, "VD_n":

$$\text{DIST.DICT} = \text{XD}_n = \text{XD}_{n-1} + [\text{VD}_n + \text{VD}_{n-1}] * \frac{1}{2} T$$

In a real system implementation, the information processing delays in the position loop become significant and must be compensated. The equality given above for "STOP.DIST" is modified as indicated for implementation in a real system:

$$\text{STOP.DIST} \geq \text{DISTTG} - \text{DIST.ERR} - n * \text{VD} * T$$

The number $n = 2$ is usually used to account for a delay of two processor cycles.

- Phase Plane Deceleration of Elevator -

In the phase plane region, a linear interpolation technique preferably is used to calculate the acceleration and velocity signals from the previously constructed tables. The distance-to-go to the target landing is used
35 to index the tables.

This is the replacement sheet

Date: 31 OCT 1991

Table building and determination of SCC have been described to this point. The matter of transitioning to Region 7 (phase plane) will now be addressed. At the transition to Region 7, the dictated velocities are inherently matched ($AD = 0$).

Distances, however, may not be matched, especially since a coordinate transformation is introduced. Distance control is shifted from distance-to-go to Look-Ahead-Distance-To-Go (LADTG). The LADTG used here is a variant of a similar quantity described in the Williams, et al. Patent 4,751,984, referred to above.

LADTG as defined below is used for the proper operation of the phase plane control, especially as the target landing is approached. The $RATIO$ is used to blend LADTG into $DISTTG$ at the target landing. The $VD_{n-1} * T_c$ term is identical to that of Williams, et al. The $MULTIPLIER$ is used to assure that LADTG matches the last distance entry stored in the phase plane tables.

$$LADTG = (DISTTG - COMPENSATION) * MULTIPLIER$$

where -

$$COMPENSATION = VD_{n-1} * T_c * RATIO$$

T_c - approximates the position loop delay and is a constant, which is adjustable in the EMS.

As the dictated velocity decreases to zero, LADTG approaches the value of $DISTTG$. The rate at which the $COMPENSATION$ term is reduced to zero is further controlled by the $RATIO$ factor.

As the elevator approaches the destination floor, the value of $RATIO$ must be gradually reduced ("washed-out") from one to zero (1 to 0). Consequently, $RATIO$ is defined as follows:

If $DISTTG > WDIST$

then $RATIO = 1$, else $RATIO = DISTTG \div WDIST$,

where "wash-out distance" ($WDIST$) is:

$$WDIST = LEVELVEL \div LEVELGAIN$$

35

This is the replacement sheet

Date: 31 OCT 1998

A linear definition is given here for RATIO. However, a nonlinear definition may be more useful in some circumstances. This is illustrated in the programmed simulation discussed below.

The MULTIPLIER is calculated only once, as the profile enters the phase plane deceleration region. It then remains constant until the end of the run.

$$\text{MULTIPLIER} = \text{XTBL}(\text{M}) \div \text{DISTTGT}$$

where -

XTBL(M) - is the last distance stored in the table, and

DISTTGT - is the actual distance-to-go at the transition point.

At the transition to the phase plane, LADTGT is forced to match the last phase plane entry:

$$\text{LADTGT} = \text{XTBL}(\text{M})$$

Subsequently computed LADTGs are then scaled by the value of the MULTIPLIER, as shown above.

For best deceleration control, MULTIPLIER values close to unity or one (1.0) are desirable.

The dictated acceleration AD and velocity VD are calculated from the phase plane table using a linear interpolation technique. LADTG is used as an indexing reference.

$$\text{AD} = \{ \text{A} - [(\text{X} - \text{LADTG}) \div (\text{X} - \text{X1})] \\ * (\text{A} - \text{A1}) \} * \text{MULTIPLIER}$$

$$\text{VD} = \text{V} - [(\text{X} - \text{LADTG}) \div (\text{X} - \text{X1})] * (\text{V} - \text{V1})$$

where -

$$\text{A} = \text{ATBL}(\text{n}), \text{V} = \text{VTBL}(\text{n}), \text{X} = \text{XTBL}(\text{n})$$

$$\text{A1} = \text{ATBL}(\text{n}-1), \text{V1} = \text{VTBL}(\text{n}-1), \text{and}$$

$$\text{X1} = \text{XTBL}(\text{n}-1)$$

After the entries in the phase table are almost used up, a linear phase plane trajectory is used based on LADTG. If an overshoot occurs, similar control is used
35 and DISTTGT is used rather than LADTG. The equations

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applicable after leaving the phase plane table but before the target landing are:

$$VD = LADTG * K$$

$$AD = - VD * K * MULTIPLIER$$

where K = the position loop gain.

If the target landing is overshoot, then Region 1 (low-level phase plane) is entered to bring the car back to the landing. However, the acceleration signal, if used for feed-forward control, is modified after the zero crossing. "AD" should either be set to zero or computed by the numerical (time) differentiation of VD:

$$AD = [VD(n) - VD(n-1)] \div T$$

where T = cycle time of processor.

- Profile Simulation -

An exemplary simulation for the profile generating system written in BASIC (Microsoft's "QuickBASIC 4.0") is presented below. In the program graphics routines used with the simulation are unnecessary for this disclosure and have been removed for purposes of simplicity. The BASIC used here is structured and reads very much like ordinary English or math statements (i.e., / = divide; * = multiply; ^ = exponent; etc.). "QuickBASIC" allows simple calls to subroutines. Also, program control may be shifted by a "GO TO" to a named label.

As can be seen, the first part of the program consists of declarative statements and comments. Next, parameters for the profile are set and preliminary computations are made. This type of operation can take place adaptively in a real elevator control to adjust for changing conditions.

Variables are initialized and flags are set. Similar operations occur in the control code used to run an elevator.

The distance for the profile is entered.

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The block of code called "READ PHASE PLANE TABLE" is bypassed, and control shifts to a point labeled "TIMED.PROFILE." Profile generation takes place on a region by region basis as described previously. "VD" and "AD" are found by numerical integration. Building of the phase-plane tables takes place next. . . There are then operations to find the dictated distance, "DIST.DICT," by numerical integration and the distance error, "DIST.ERR."

Next, the stopping distance is found by a call to the subroutine called "STOPD." Then a check is made if $SCC\% = 1$, meaning a stopping sequence should be initiated. The "SCC" determination is based on "DISTTG," as computed below, "DIST.ERR," and the dictated velocity "VD."

Control then shifts to the label "VELCONTROL:" . The subroutine "VELCONTROL" is called to simulate in simplified form the operation of the EMS of Figure 1 (a model of a DC drive may be used). This subroutine provides an update to the actual velocity and acceleration. Importantly, it provides the "DIST.GONE" (actual distance traveled by the elevator). From "DIST.GONE" the "DISTTG" is computed.

The simulation continues with a timed-based profile being generated until $SCC\% = 1$. The stopping sequence then commences. For other than a long run, this includes further operation with a timed profile, until a condition of zero acceleration is reached. This is analogous to operation in Region 5, which is commented as "SCC ACTIVE".

When $AD = 0$, control shifts to the label near the beginning of the program entitled "PP.PROFILE" - READ PHASE PLANE TABLE." The distance range for the tables is first matched to the "LADTG" (found by a call to a subroutine). The match is made using the parameter
35 called "MULTIPLIER." The "MULTIPLIER" is computed only once during a run. Next, reading of the velocity and

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acceleration tables occurs, using an interpolation algorithm.

The phase plane changes to a straight line definition when the table index $N\% = 1$ (table exhausted). A region called "LOWLEV.PROFILE" is then defined. The simulation differs from the actual profile generator in that Region 1 here applies only to the end of the run and that the same phase-plane slope is used for table continuation and for recovery from overshoots.

This is the replacement sheet

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- EXEMPLARY BASIC PROGRAM -

```
DECLARE SUB LADISTANCE (LADTG, MULTIPLIER, RDISTANCE,
    distance, VD, DISTTG, DELTATC, LOWLEV%)
DECLARE SUB VELCONTROL (VDICT!, AM!, VM!, XM!, DT!, T!,
    RESETFLAG%, DRIVELIM)
DECLARE SUB STOPD (XSTART, VSTART, AD, XSTOP, VMAX,
    DECELRTIO, JERK)
    TITLE: NEWVEL
    COPYRIGHT: OTIS ELEVATOR COMPANY
    DATE WRITTEN: 2/15/88
    LANGUAGE: QUICK BASIC 4.0
    PURPOSE: SIMULATE NEW MCSS NORMAL PROFILE GENERATOR
    ***** ARRAYS FOR PHASE PLANE TABLE IN MAIN MODULE
    DIM PPV(600), PPS(600), PPA(600)
    ***** ARRAYS FOR GRAPHING SUBROUTINE GRAF1
    DIM PARR(4, 600), SF1(4), SF(4), GAIN(4)
    ***** INIT SCREEN, SET SCREEN TYPE TO 2 (CGA), 9 (EGA),
    OR 10 (MONO)
CLS : SCREEN 0, 0, 0: COLOR 7, 0, 0: KEY OFF: SCRN = 9
    ** SET PARAMETERS FOR PROFILE AND COMPUTE RELATED VALUES
ACCELLIMIT = 1200 'ACCELERATION LIMIT
JERKLIMIT = 2400 'JERK LIMIT DURING ACCELERATION
DECELRTIO = 1! 'RATIO OF DECELERATION TO ACCELE-
    TION
VELLIMIT = 6000 'MAX SPEED, CONTRACT VELOCITY, ETC.
LEVELGAIN = 3! 'LEVELING GAIN (POSITION LOOP GAIN)
DELTAT = .04: DELTATC = .1: 'CYCLE TIME AND TIME DELAY
    IN VELOCITY CONTROL
STOPTOLV = 40: STOPTOLS = 6: 'THESE DEFINE CONDITION FOR
    BRAKE DROP
VELLIMIT1 = 1.01 * VELLIMIT 'USED FOR SPEED CHECK
VBASE = 4800 'VELOCITY AT WHICH ACCELERATION IS REDUCED
    AT JERKBASE RATE
    VBASE<VELLIMIT TO BE EFFECTIVE
DELTAACCELS = JERKLIMIT * DELTAT / 2 'ACCEL. INCRE. FOR
    TESTING ACCEL.
    REDUCTION
    ***** INITIALIZE VARIABLES AND SET FLAGS
REGION% = 2 ' START RUN IN REGION 2
50 RESETFLAG% = 1 ' CAUSE VELCONTROL SUBROUTINE TO INITIAL-
    IZE ON FIRST PASS
TSTOP = 999 ' FLAG AND REGISTER FOR STOPPING TIME
    WITHIN STOPTOLS AND STOPTOLV
```

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```

VD = 0: AD = 0 ' INITIAL DICTATED VELOCITY AND ACCELERA-
' TION
BUILD.TABLE% = 1 ' TABLE IS BUILT WHEN RUN STARTS UNTIL
' AD = 0
5 READ.TABLE% = 0 ' TABLE IS READ DURING PHASE PLANE
' DECELERATION TO LANDING
SCC% = 0 ' STOP CONTROL COMMAND = 1 STARTS
' STOPPING SEQUENCE
DIST.GONE = 0 ' START AT ZERO POSITION
CLOCK = 0 ' START AT ZERO TIME
PPI% = 0 ' INITIAL INDEX FOR TABLE
PPV(PPI%) = 0: PPS(PPI%) = 0: PPA(PPI%) = 0 ' INITIAL
' VALUES OF
' TABLE
MATCHFLAG% = 1 ' FLAG TO COMPUTE MULTIPLIER ON FIRST PASS
' READING TABLE
MULTIPLIER = 1 ' USED FOR PERFECT MATCH OF VELOCITY TABLE
' TO CURRENT VELOCITY
LOWLEV% = 0 ' LOWLEVEL PHASE PLANE WHEN LOWLEV%=1,
' NO LOWLEVEL OTHERWISE
LLTIME% = 0 ' FLAG TO CAPTURE START OF LOW LEVEL
' OPERATION
VELMAXFLAG% = 0 ' FLAG TO CONTROL PROFILE WHERE VELMAX(SUB
' STOPD) DETERMINES SCC
distx = 0
' BRAKE LIFTED AT START OF RUN; BRAKE DROPPED AT T=FLTTIME
' ***** PARAMETERS REQUIRED FOR GRAF1 SUBROUTINE
'
SP = 1: FOR I = 0 TO 3: GAIN(I) = 1: NEXT I: GAIN(4) =
100
XSCALE = 1: XSTART = 0
FOR I = 0 TO 4: PARR(I, 0) = 0: NEXT I
' SCREEN PRINT OF PARAMETERS AND INPUT OF RUN DISTANCE
'
LOCATE 10, 1: INPUT "DISTANCE FOR RUN (mm) (3658 mm
default)= "; distance
IF distance = 0 THEN distance = 3658
DISTTG = distance
RUN.DISTANCE = distance
LOCATE 12, 1: PRINT "DISTANCE FOR RUN = ", distance
'
GOTO TIMED.PROFILE
' ***** GOTO TIMED PROFILE *****
50 PP.PROFILE:
' ***** READ PHASE PLANE TABLE *****
'
IF READ.TABLE% = 0 THEN
GOTO TIMED.PROFILE

```

This is the replacement sheet

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```
ELSEIF LOWLEV% = 1 THEN
    GOTO LOWLEV.PROFILE
END IF
'
5 ' READ VELOCITY AND ACCELERATION FROM PHASE PLANE TABLE
'
BUILD.TABLE% = 0

' GO COMPUTE LADTG
'
CALL LADISTANCE(LADTG, MULTIPLIER, RDISTANCE, distance,
VD, DISTTG, DELTATC, LOWLEV%)
'
'MATCH OF TABLE TO LADTG
'
IF MATCHFLAG% >= 1 THEN
    MULTIPLIER = PPS(PPI%) / LADTG
    MATCHFLAG% = 0
    LADTG = PPS(PPI%)
    END IF
'
'
DO UNTIL PPS(PPI% - 1) <= LADTG
PPI% = PPI% - 1
IF PPI% <= 1 THEN
    LOWLEV% = 1
    GOTO LOWLEV.PROFILE
END IF
LOOP
'
'
SRATIO = (PPS(PPI%) - LADTG) / (PPS(PPI%) - PPS(PPI% -
1))
VD = (PPV(PPI%) - (PPV(PPI%) - PPV(PPI% - 1)) * SRATIO)
AD = -(PPA(PPI%) - (PPA(PPI%) - PPA(PPI% - 1)) * SRATIO)
* MULTIPLIER
'
'
GOTO VELCONTROL
'***** GOTO VELCONTROL SIMULATION *****
'
LOWLEV.PROFILE:
'***** CONTINUE PHASE PLANE AT END OF RUN *****
'
CALL LADISTANCE(LADTG, MULTIPLIER, RDISTANCE, distance,
VD, DISTTG, DELTATC, LOWLEV%)
'
VD = LADTG * LEVELGAIN
AD = -VD * LEVELGAIN * MULTIPLIER
'
50 GOTO VELCONTROL
'***** GOTO VELCONTROL SIMULATION *****
'
'
```

This is the replacement sheet

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```

TIMED.PROFILE:
'***** GENERATE TIMED PROFILE DURING AD AND *****
'***** WHILE RUNNING AT CONTRACT (CONSTANT) SPEED *****
'
5 ON REGION% GOTO REGION2, REGION2, REGION3, REGION4,
  REGION5, REGION6
'
'
REGION2:          'START HERE --- JERK IS CONSTANT
'
JERK = JERKLIMIT
'
'***** VERY LOW SPEED PROFILE SETS VELMAXFLAG% *****
'***** (VELMAX COMES FROM STOPPING DISTANCE SUB-
'          -ROUTINE) *****
'
IF VELMAX >= VELLIMIT - AD * DELTAT THEN
    VELMAXFLAG% = 1
    REGION% = 4
    GOTO REGION4
END IF
'
IF AD >= ACCELLIMIT THEN
    REGION% = 3
    GOTO REGION3
ELSEIF SCC% = 1 THEN
    REGION% = 5
    GOTO REGION5
END IF
GOTO START.INTEG
'
REGION3:          'CONSTANT ACCELERATION
'
JERK = 0
AD = ACCELLIMIT
'
IF VELMAX >= VELLIMIT - AD * DELTAT THEN
    VELMAXFLAG% = 1
    REGION% = 4
    GOTO REGION4
END IF
'
IF VD >= VBASE THEN
    REGION% = 4
    GOTO REGION4
ELSEIF SCC% = 1 THEN
    REGION% = 5
    GOTO REGION5
END IF
50 GOTO START.INTEG
'
REGION4:          'HIGH SPEED ACCELERATION REDUCTION
'
'***** COMPUTE JERK DYNAMICALLY *****

```

This is the replacement sheet

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```
JERK = -AD ^ 2 / (2 * (VELLIMIT - VD))
DELTAACCEL = -JERK * DELTAT / 2
5 IF VD >= VELLIMIT1 OR AD <= DELTAACCEL THEN
    REGION% = 6
    BUILD.TABLE% = 0
    DIST.ERRMAX = DIST.ERR
    GOTO REGION6
ELSEIF SCC% = 1 THEN
    REGION% = 5
    GOTO REGION5
END IF
GOTO START.INTEG
REGION5:      'SCC ACTIVE
JERK = -JERKLIMIT
IF AD < DELTAACCEL5 THEN
    JERK = 0
    AD = 0
    READ.TABLE% = 1
    BUILD.TABLE% = 0
    END IF
GOTO START.INTEG
REGION6:      'RUN AT CONTRACT SPEED
JERK = 0
AD = 0
VD = VELLIMIT
IF SCC% = 1 THEN
    READ.TABLE% = 1
    GOTO PP.PROFILE
END IF
START.INTEG:
'***** FIND DICTATED AD AND VD FROM JERK *****
LOCATE 17, 1: PRINT "REGION = ", REGION%, SCC%,
DIST.GONE
PREVA = AD
AD = AD + JERK * DELTAT
IF AD > ACCELLIMIT THEN AD = ACCELLIMIT
IF AD < 0 AND READ.TABLE% = 0 THEN AD = 0
VD = VD + ((AD + PREVA) / 2) * DELTAT
'***** BUILD PHASE PLANE TABLE DURING ACCELERATION *****
50 IF BUILD.TABLE% = 1 THEN
    PPI% = PPI% + 1
    PPV(PPI%) = VD
ELSEIF READ.TABLE% = 1 THEN
```

This is the replacement sheet

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```
GOTO PP.PROFILE
ELSE
  GOTO STOPDIST
END IF
5 '
' **** BUILD TABLE ON STRAIGHT LINE TRAJECTORY -
'   - TEST FOR LOW SPEED PROFILE *****
'
LEVELVEL = (DECELRTIO * (AD + J * DELTAT)) / LEVELGAIN
RDISTANCE = LEVELVEL / LEVELGAIN' DISTANCE FOR WASHOUT
RATIO IN LADTG
IF PPV(PPI%) < LEVELVEL AND SCC% = 0 AND VELMAXFLAG% = 0
THEN
  PPS(PPI%) = PPV(PPI%) / LEVELGAIN
  PPA(PPI%) = PPV(PPI%) * LEVELGAIN
ELSE
  PPS(PPI%) = PPS(PPI% - 1) + (PPV(PPI%) + PPV(PPI% -
1)) * DELTAT / (2 * DECELRTIO)
  PPA(PPI%) = (AD * DECELRTIO + PPA(PPI% - 1)) / 2
END IF
'
DIST.DICT = DIST.DICT + (PPV(PPI%) + PPV(PPI% - 1)) *
DELTAT / 2
DIST.ERR = DIST.DICT - DIST.GONE
'
STOPDIST:
' ***** FIND STOPPING DISTANCE TO DETERMINE SCC *****
'
IF SCC% <> 0 THEN GOTO VELCONTROL
'
' COMPUTE STOPPING DISTANCE
'
IF REGION% = 6 THEN
  STOPDIST = PPS(PPI%)
  DIST.ERR = DIST.ERRMAX
ELSE
  CALL STOPD(PPS(PPI%), VD, AD, STOPDIST, VELMAX,
DECELRTIO, -JERKLIMIT)
END IF
' CHECK FOR STOP CONTROL POINT
'
'
IF STOPDIST >= DISTTG - DIST.ERR - 2 * DELTAT * VD THEN
  SCC% = 1
ELSE
  SCC% = 0
END IF
'
VELCONTROL:
50 ' ***** SIMULATE VELOCITY CONTROL SYSTEM *****
'
' SIMULATE VELOCITY CONTROL (DC-DBSS)
'
```

This is the replacement sheet

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```
CALL VELCONTROL(VD, AM, VACTUAL, DIST.GONE, DELTAT,  
CLOCK, RESETFLAG%, DRIVELIM)  
DISTTG = distance - DIST.GONE  
,  
5 LOCATE 20, 1: PRINT USING "ELAPSED TIME = ##.##"; CLOCK  
,  
'***** PREPARE FOR GRAPHING OUTPUT *****  
'FILL PLOT ARRAY  
,  
PARR(0, SP) = AD  
PARR(1, SP) = AM  
PARR(2, SP) = VD  
PARR(3, SP) = VACTUAL  
PARR(4, SP) = DISTTG  
,  
,  
LOCATE 18, 5: PRINT "DISTTG, DIST.ERR = ", INT(DISTTG),  
INT(DIST.ERR)  
,  
'SET SCALE FACTORS FOR PLOT  
,  
FOR I = 0 TO 4  
IF ABS(PARR(I, SP)) > SF1(I) THEN  
    SF1(I) = ABS(PARR(I, SP))  
END IF  
NEXT I  
SP = SP + 1  
,  
'EQUALIZE SCALE FACTORS  
,  
IF SF1(0) > SF1(1) THEN SF1(1) = SF1(0) ELSE SF1(0) =  
SF1(1)  
IF SF1(2) > SF1(3) THEN SF1(3) = SF1(2) ELSE SF1(2) =  
SF1(3)  
,  
'***** PROCESS SIMULATION CONTINUATION AND TERMINATION **  
,  
IF VACTUAL <= STOPTOLV AND DISTTG <= STOPTOLS AND TSTOP  
= 999 THEN  
    TSTOP = CLOCK + 1  
    FLTIME = CLOCK  
ELSEIF DISTTG <= -76 THEN  
    GOTO FINISH  
    FLTIME = 0  
END IF  
,  
,  
IF CLOCK < TSTOP THEN  
    IF BUILD.TABLE% = 1 AND READ.TABLE% = 0 THEN  
50        GOTO TIMED.PROFILE  
    ELSEIF BUILD.TABLE% = 0 AND READ.TABLE% = 0 THEN  
        GOTO TIMED.PROFILE  
    ELSE  
        GOTO PP.PROFILE
```

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```
        END IF
    END IF
    |
    FINISH:
    | ***** STOP SIMULATING AND START GRAPHING *****
    |
    IF LOWLEV% = 1 AND LLTIME% = 0 THEN
        LOCATE 22, 1, 0
        PRINT USING "LOW LEV AT ##.##"; CLOCK
        LLTIME% = 1
    END IF
    |
    LOCATE 21, 1: PRINT USING "FLIGHT TIME = ##.##"; FLTIME
    LOCATE 24, 1, 1: PRINT "PRESS ANY KEY FOR PLOT...";
    BEGIN: X$ = INKEY$: IF X$ = "" THEN GOTO BEGIN
    |
    | ***** CALL THE GRAPHING SUBROUTINE *****
    |
    | CALL GRAF1(PARR(), GAIN(), SF(), SF1(), XSCALE, XSTART,
    | SCRN, SP, DELTAT)
    | END
    |
    SUB LADISTANCE (LADTG, MULTIPLIER, RDISTANCE, distance,
    | VD, DISTTG, DELTATC, LOWLEV%)
    |
    LOCATE 16, 5: PRINT "multiplier= "; MULTIPLIER
    | ***** DESCRIPTION *****
    | LOOK AHEAD DISTANCE TO GO COMPENSATES FOR SOME CONTROL
    | SYSTEM DELAYS
    | IT IS DISABLED FOR THE CONDITIONS INDICATED BELOW
    | THE MULTIPLIER IS REQUIRED FOR MATCHING OF DISTANCES
    | PRIOR TO READING OF THE PHASE PLANE TABLE
    |
    |
    IF distance > 1000 AND VD > 0 AND LOWLEV% = 0 THEN
        IF DISTTG < RDISTANCE THEN
            RATIO = ABS(DISTTG / RDISTANCE) ^ .25
        ELSE
            RATIO = 1
        END IF
        VELDEL = VD * DELTATC * RATIO
    ELSE
        VELDEL = 0
    END IF
    |
    LADTG = (DISTTG - VELDEL) * MULTIPLIER
    |
    |
    END SUB
    |
    SUB STOPD (XSTART, VSTART, AD, XSTOP, VMAX, DECELRTIO,
    | JERK)
    | COMPUTATIONS RELATED TO STOPPING DISTANCE SEQMENT
    |
```

50

This is the replacement sheet

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'The computation is performed in two parts: 1) From
' VSTART (jerkout point) to the velocity peak VMAX.
' 2) From VMAX back to a speed equal to VSTART.
' It can be shown that the time in the second region
5 ' is equal to the time in the first region divided by
' the DECELRTIO. XSTART is the distance stored away
' in the distance table as PPS(PPI%).

'The equations for velocity and distance given below are
' based on successive integration of jerk to yield
' acceleration, velocity, and distance.

T = -AD / JERK
T2 = T * T
T3 = T2 * T
VMAX = VSTART + AD * T + JERK * T2 / 2
X2 = XSTART + VSTART * T + AD * T2 / 2 + JERK * T3 / 6
'
'
JERKDECEL = JERK * DECELRTIO ^ 2
T = T / DECELRTIO
T3 = T ^ 3
XSTOP = X2 + VMAX * T + JERKDECEL * T3 / 6
'

END SUB

SUB VELCONTROL (VDICT, AM, VM, XM, DT, T, RESETFLAG%,
DRIVELIM) STATIC

'This is a simple DC direct drive model that includes
' torque limiting (expressed in acceleration units)
' and generation of a drive limit signal.

'The driven load is assumed to be a pure inertia and a
' proportion-integral controller is used.

' ***** see last portion of subroutine for model
' description *****

'VDICT= VELOCITY DICTATION

'AM= MACHINE ACCELERATION

'VM= MACHINE VELOCITY

'XM= MACHINE POSITION

'INITIAL CONDITIONS ON INTERNAL STATE VARIABLE EG1=0

'DT= CYCLE TIME

'T= ELAPSED TIME

'TF= TIME CONSTANT OF LAG FILTER THAT PRECEDES VELOCITY
' CONTROL

'RESETFLAG% >= 1 CAUSES REINITIALIZATION

'***** INITIALIZE ON FIRST PASS THROUGH *****

IF RESETFLAG% >= 1 THEN

50 GAIN = 10 'INTEGRAL GAIN
 RESPONSE = 1! 'PROPORTIONAL GAIN/INTEGRAL GAIN
 ALIMPOS = 1400 ' POS TORQUE LIMIT IN ACCELE-
 TION UNITS
 ALIMNEG = 1400 ' NEG TORQUE LIMIT IN ACCELE-
 TION UNITS

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```

      LIMFRAC = .8      'FRACTION OF DRIVE LIMITS CAUSING
      '                DRIVE LIMIT SIGNAL
      TFILTER = .05    'TIME CONSTANT OF LAG FILTER THAT
      '                PRECEDES VELOCITY CONTROL

      EG1 = 0
      CFILT1 = EXP(-DT / TFILTER)
      CFILT2 = 1 - CFILT1
      GAINRESPONSE = GAIN * RESPONSE
      GAINDT = GAIN * DT
      RESETFLAG% = 0
      AMOLD = 0
      VMOLD = 0

ELSE
      GOTO STARTINTEG
END IF
'
'***** RUN THE INTEGRATION AFTER INITIALIZING *****
'
STARTINTEG:
VFIL = VFIL * CFILT1 + VDICT * CFILT2
E1 = VFIL - VM
EG1 = EG1 + E1 * GAINDT
EG2 = E1 * GAINRESPONSE + EG1
E2 = EG2 - VM
IF E2 <= LIMFRAC * ALIMPOS AND E2 >= -LIMFRAC * ALIMNEG
THEN DRIVELIM = 0 ELSE DRIVELIM = 1
IF E2 <= ALIMPOS AND E2 >= -ALIMNEG THEN AM = E2 ELSE IF
E2 > ALIMPOS THEN AM = ALIMPOS ELSE AM = -ALIMNEG
VM = VM + (AM + AMOLD) * (DT / 2)
AMOLD = AM
XM = XM + (VM + VMOLD) * (DT / 2)
VMOLD = VM
T = T + DT
'
'***** DESCRIPTION OF MODEL *****
'BLOCK DESCRIPTION          INPUTS      OUTPUTS
'INPUT LAG FILTER;TFILTER=TIME CONSTANT VDICT      VFIL
'SUMMING BLOCK              VFIL,-VM E1
'PROPORTIONAL CONTROLLER ;GAIN*RESPONSE E1          EG3
'INTEGRAL CONTROLLER ; GAIN*DT      E1            EG1
'SUMMING BLOCK              EG1,EG3      EG2
'SUMMING BLOCK              EG2,VM      E2
'LIMITER ;ALIMPOS & ALIMNEG      E2          AM
'INTEGRATOR ; TRAPEZOIDAL INTEG.    AM          VM
'INTEGRATOR ; TRAPEZIODAL INTEG.    VM          XM
'
END SUB

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Although this invention has been shown and described with respect to detailed, exemplary embodiments thereof, it should be understood by those skilled in the art that various changes in form, detail, methodology and/or approach may be made without departing from the spirit and scope of this invention.

Having thus described at least one exemplary embodiment of the invention, that which is new and desired to be secured by Letters Patent is claimed below.

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Claims

1. A method of elevator speed dictation control for controlling elevator velocity of an elevator car from zero to a maximum velocity and back to zero in an elevator system based on a velocity profile, comprising:

using a velocity profile in which each segment of the velocity profile is generated at one of the limits which constrain the system; viz., at maximum jerk, maximum acceleration, maximum velocity, maximum position or loop gain, or maximum motor torque.

2. The elevator speed dictation control method of Claim 1, wherein there is included the step(s) of:

generating the acceleration portion of the velocity profile in an open loop manner, beginning with constant (maximum) jerk, transitioning to constant (maximum) acceleration after an acceleration limit is attained, and jerking out (negative jerk) at a constant rate to maximum (contract) velocity when the maximum velocity is nearly attained.

3. The elevator speed dictation control method of Claim 1 or 2, wherein there is included the step(s) of:

storing the velocity data in a table as a function of distance gone during acceleration, allowing the table to be used in reverse to find dictation as a function of distance to go during deceleration.

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4. The elevator speed dictation control method of Claim 3, wherein there is included the step(s) of:

building the velocity table from acceleration and jerk constraints so that the acceleration corresponding to each velocity is known and storing the acceleration information along with the velocity information in tables having distance as the independent variable.

5. The elevator speed dictation control method of Claim 3 or 4, wherein there is included the step(s) of:

making the table entries during each processor cycle during acceleration.

6. The elevator speed dictation control method of any one of claims 3 to 5, wherein there is included the step(s) of:

using the acceleration table in reverse together with a numerical scaling to decelerate the elevator.

7. The elevator speed dictation control method of any one of claims 1 to 6, wherein there is further included the step(s) of:

outputting the acceleration information by the profile generator at all times, including acceleration, constant speed, deceleration.

8. The elevator speed dictation control method of any one of claims 1 to 7, wherein there is included the step(s) of:

finding acceleration without any numerical differentiation of velocity.

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9. The elevator speed dictation control method of any one of claims 1 to 8, wherein there is included the step(s) of:

blending the acceleration signal with the velocity signal and applying the combination as a dictation to a drive for the elevator car, providing an "acceleration feedforward" that reduces velocity tracking time, making the drive more responsive.

10. The elevator speed dictation control method of any one of claims 1 to 9, wherein there is included the step(s) of:

providing a proportional-integral controller used in the drive for the elevator car; and

compensating for load sensitivity by varying the proportional gain of the proportional-integral controller as a function of load weight.

11. The elevator speed dictation control method of any one of claims 1 to 10, wherein there is included the step(s) of:

using an algorithm for computing stopping distance, in which the stopping distance is computed based on the DICTATED profile and comparing stopping distance to DISTTG (distance to go; DRIVE OUTPUT COORDINATES) converted to DICTATION coordinates.

12. The elevator speed dictation control method of Claim 11, wherein there is included the step(s) of:

measuring the distance tracking error by numerically integrating the dictated velocity to find the distance dictated; and

accomplishing the conversion of DISTTG to DICTATION coordinates by subtracting tracking distance error from DISTTG in which the

DISTANCE GONE = LENGTH OF RUN - DISTTG, and
DISTANCE DICTATED - DISTANCE GONE = DISTANCE
TRACKING ERROR.

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13. The elevator speed dictation control method of Claim 12, wherein there is included the step(s) of:
issuing a stop control command (SCC) when the following condition is true -

$$\text{STOPPING DIST.} \geq \text{DISTTG} - \text{DIST. ERROR} - \\ (N * \text{VEL} * \text{DELTAT})$$

wherein STOPPING DIST. is computed; DISTTG comes from a position transducer; DIST. ERROR is also measured; and N accounts for a number of cycles of the order of about two (2) of delay in the processor system, VEL is dictated velocity and DELTAT is the processor cycle time.

14. The elevator speed dictation control method of any one of claims 1 to 13, wherein there is included the step(s) of:
decelerating the elevator with look-ahead-distance-to-go (LADTG) as the independent variable; and
using a multiplier in the profile generator as a scaling factor that acts on the LADTG to make it equal to the distance range for the velocity and acceleration tables.

15. The elevator speed dictation control method of Claim 14, wherein there is included the step(s) of:
making the look-ahead-distance-to-go (LADTG) adaptive and, as the end of a run is approached, using a "washout" term for LADTG which is a function of DISTTG;
and

as DISTTG approaches zero, using a multiplier to act on the velocity dependent portion of LADTG to make that term less and less significant.

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16. The elevator speed dictation control method of Claim 15, wherein there is included the step(s) of:
reverting phase plane control to pure DISTTG, should the control overshoot and the DISTTG go negative, and discontinuing use of LADTG as the independent variable.

17. The elevator speed dictation control method of any one of claims 1 to 16, wherein there is included the step(s) of:
making the profile generator adaptive by presetting the acceleration and jerk limits based on the load in the elevator cab by a computation based on load weight made at the beginning of a run.

18. The elevator speed dictation control method of any one of claims 1 to 17, wherein there is included the step(s) of:
reducing acceleration at a speed close to the base speed of the motor, keeping power requirements well bounded without significantly compromising flight time, as a form of acceleration profile adaptation based on speed.

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Date: 31 OCT 1946

Abstract

ELEVATOR SPEED DICTATION SYSTEM

An elevator speed dictation system for controlling the elevator velocity from zero to a maximum velocity and back to zero, illustrated in functional block form in Fig. 1. Velocity profiles over eight regions (Regions 0-7) are provided for zero speed (0), low level phase plane (1), constant jerk to prescribed acceleration (2), prescribed acceleration (3), constant jerk down to constant velocity (4), jerk level after generation of Stop Control Command (SCC; 5), constant speed (6), and phase plane (7), respectively. Velocity profiles for Regions 0-7, including traces of velocity (10), velocity dictated (20), acceleration (30), dictated acceleration (40) and distance to go (50) versus time are graphically illustrated in Fig. 2 & Figs. 4-6 for a long elevator car run, Intermediate II (transition to Region 5 occurs after SSC), Intermediate I (transition occurs from Regions 3 to 5), and a short elevator car run, respectively; while Fig. 7 illustrate velocity and acceleration curves used to find the stopping distance. Fig. 3 provides a flow chart for the transitions between the various regions (0-7) of the profiles.

Figure 7

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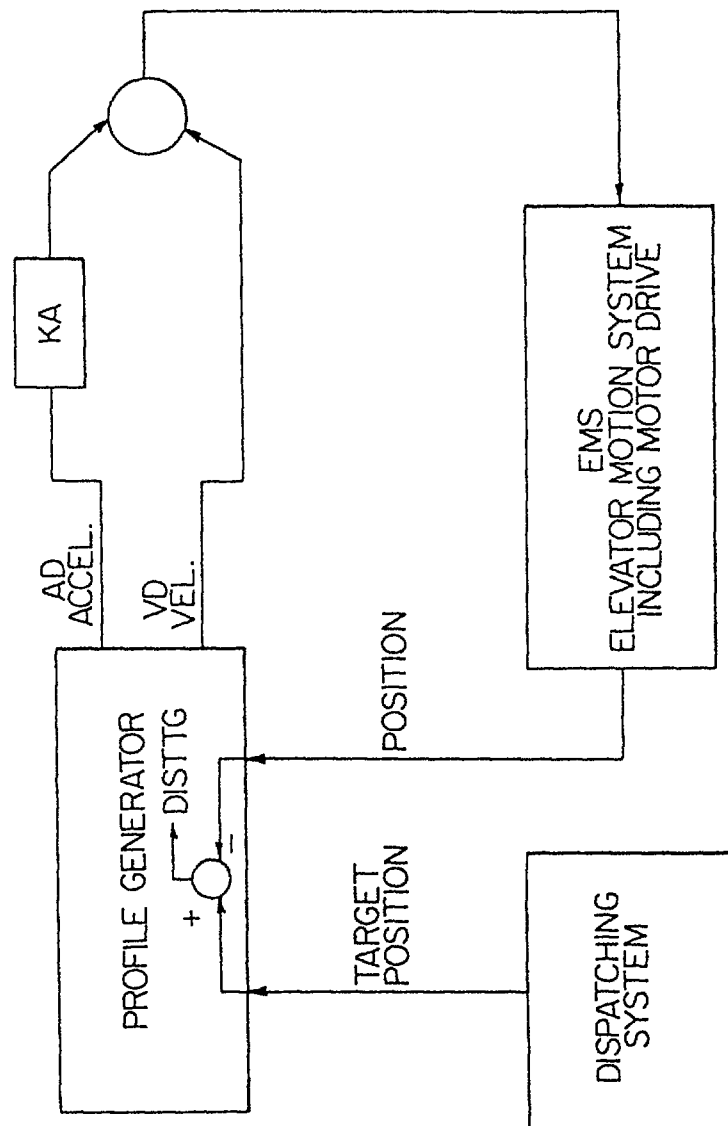
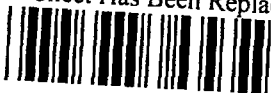


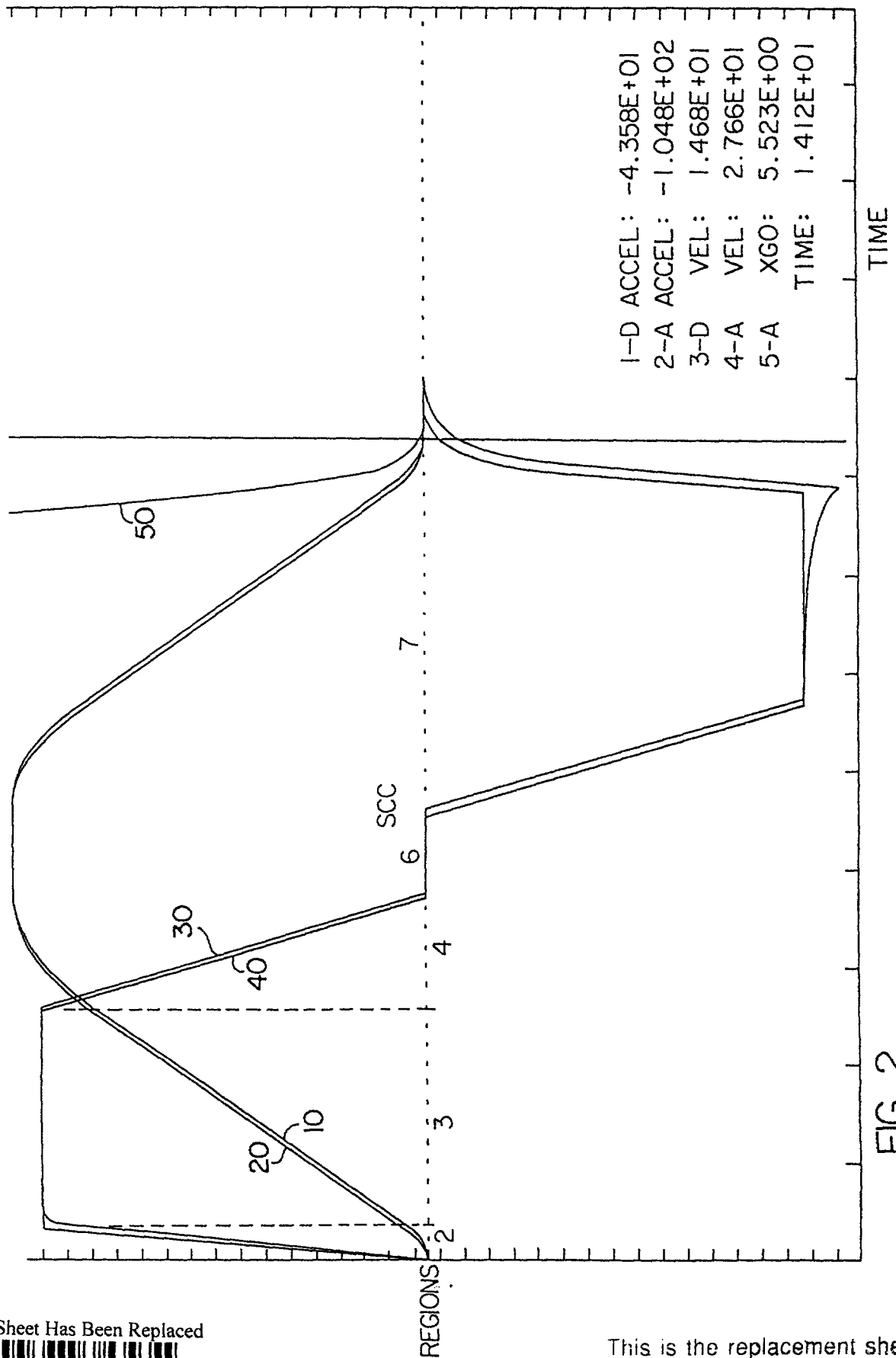
FIG. 1

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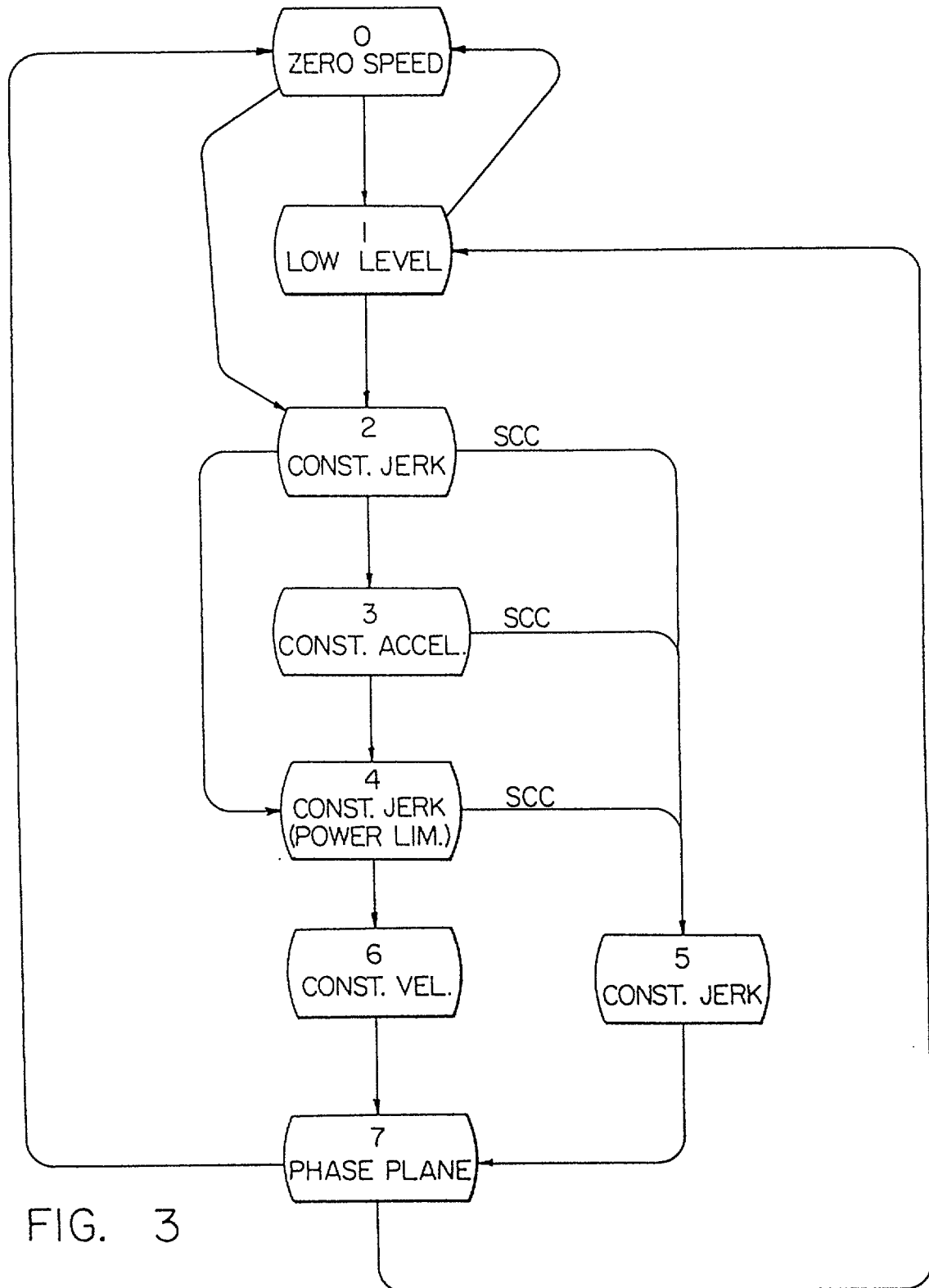


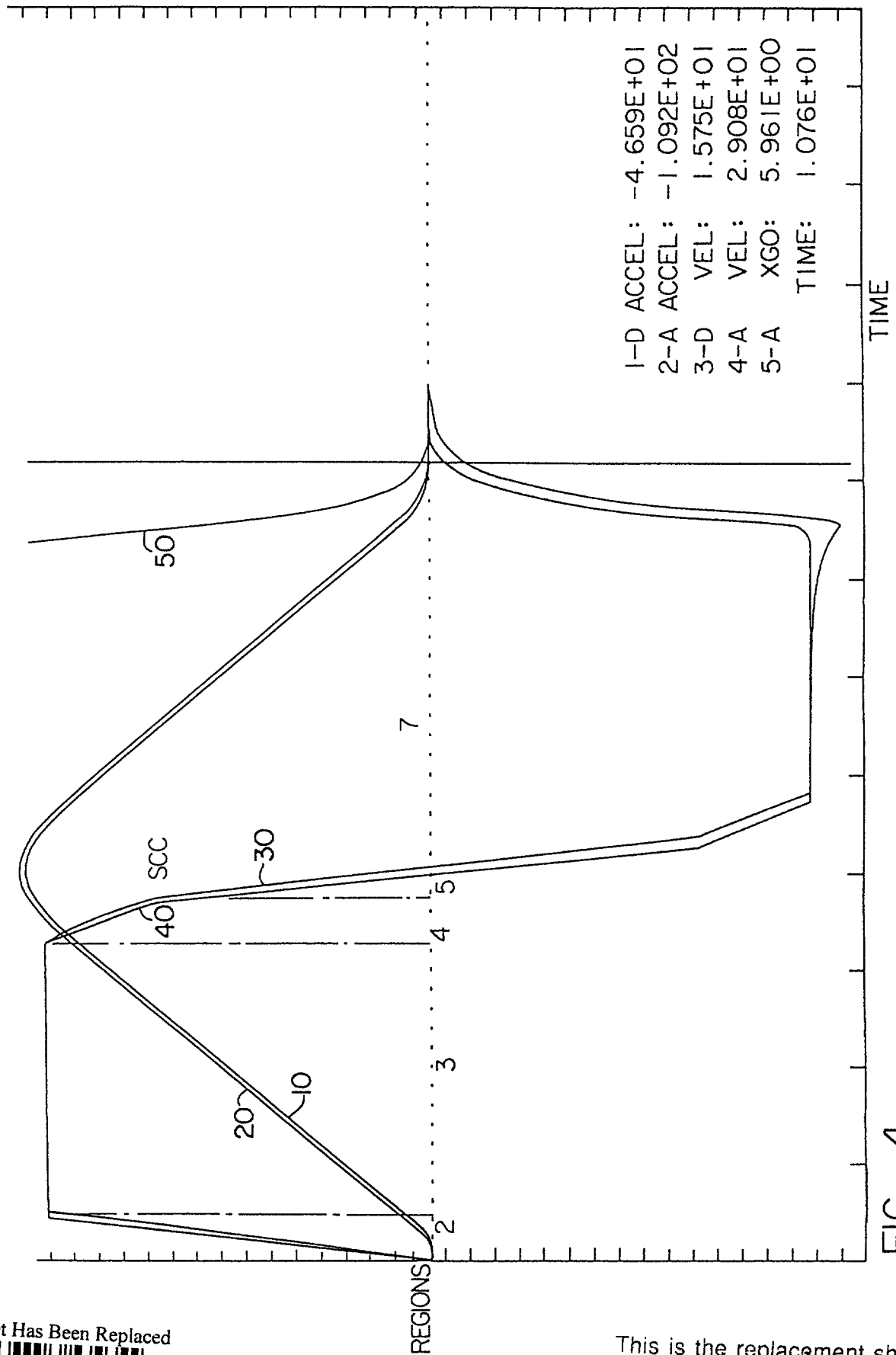
FIG. 3

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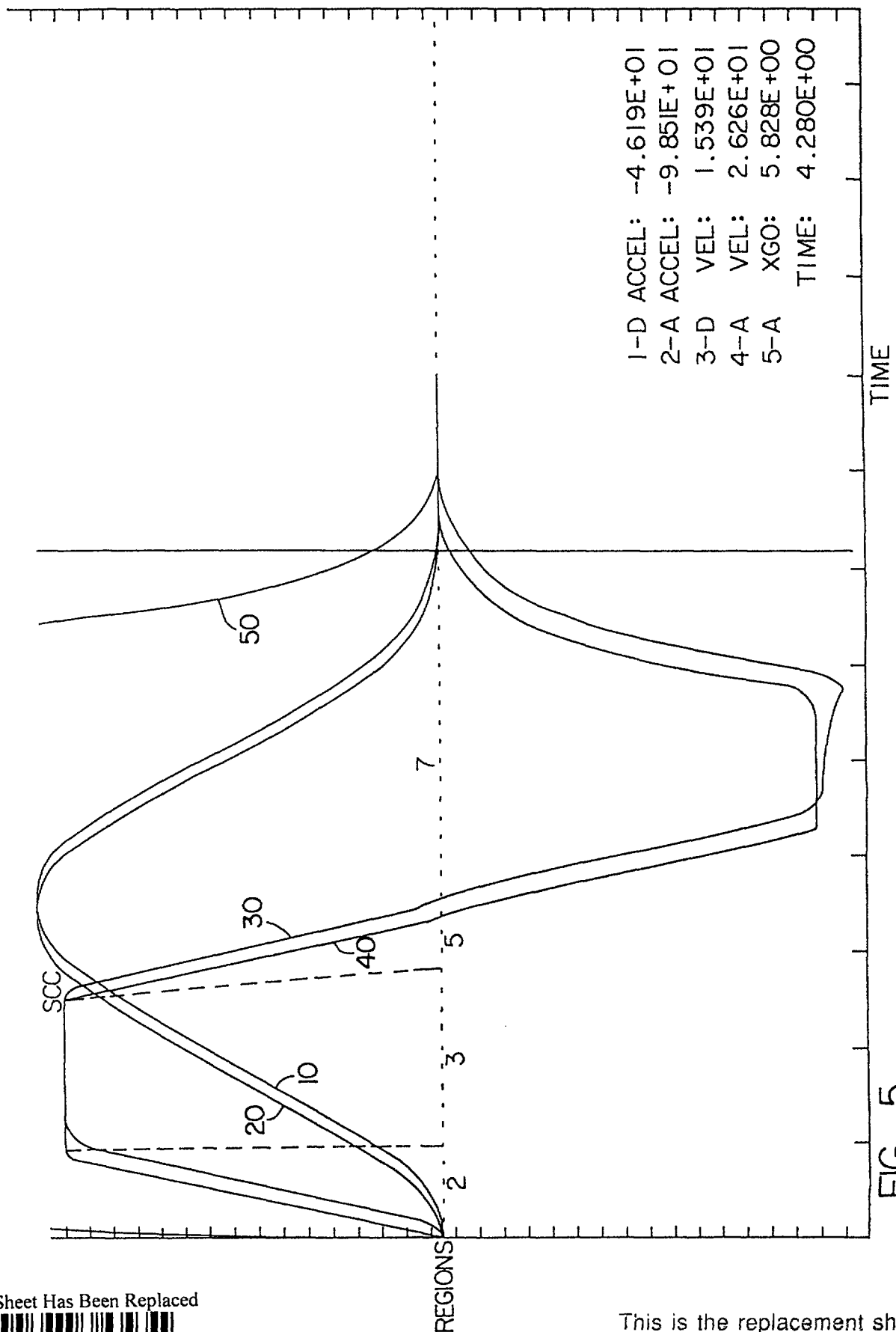


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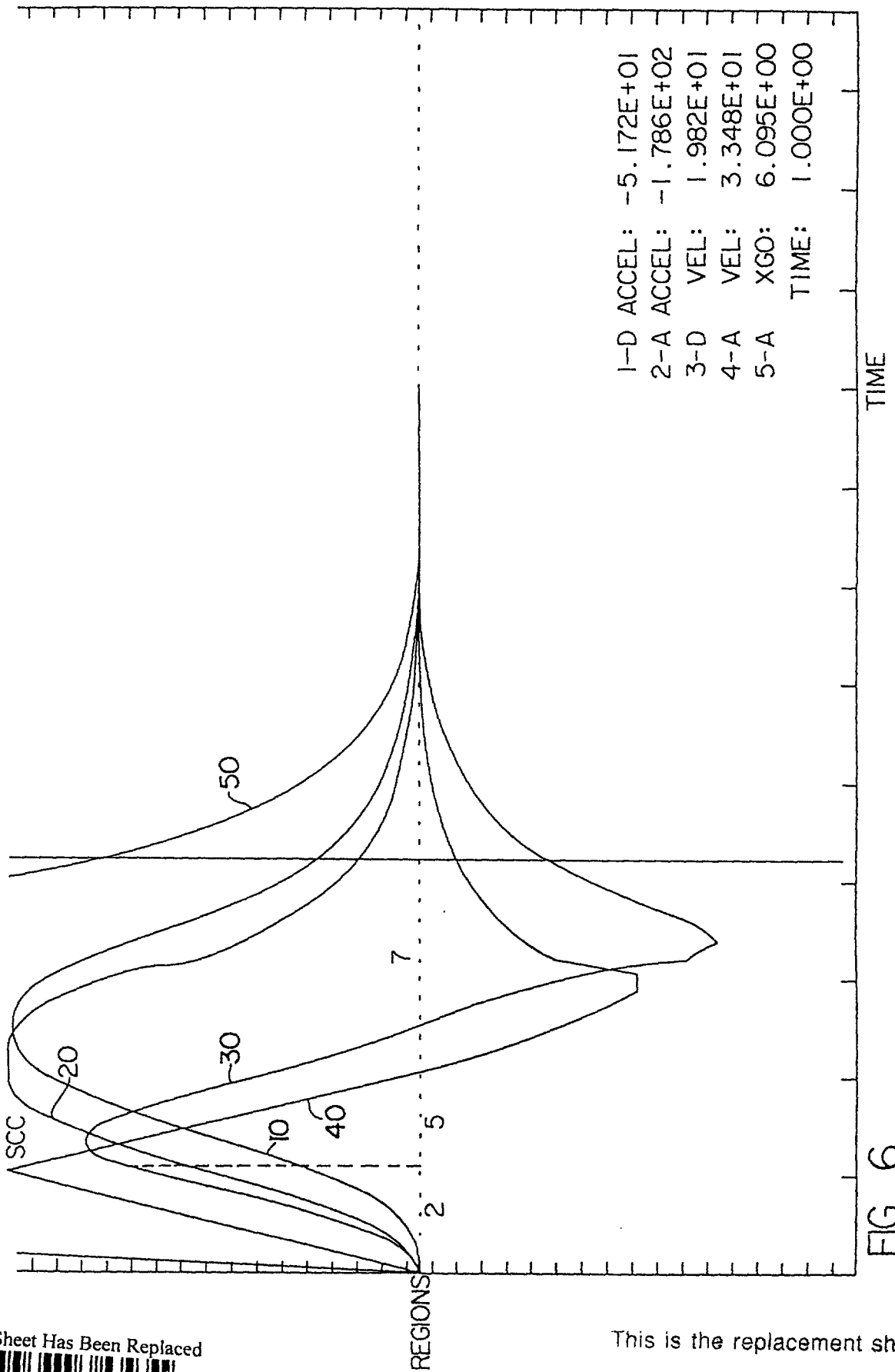


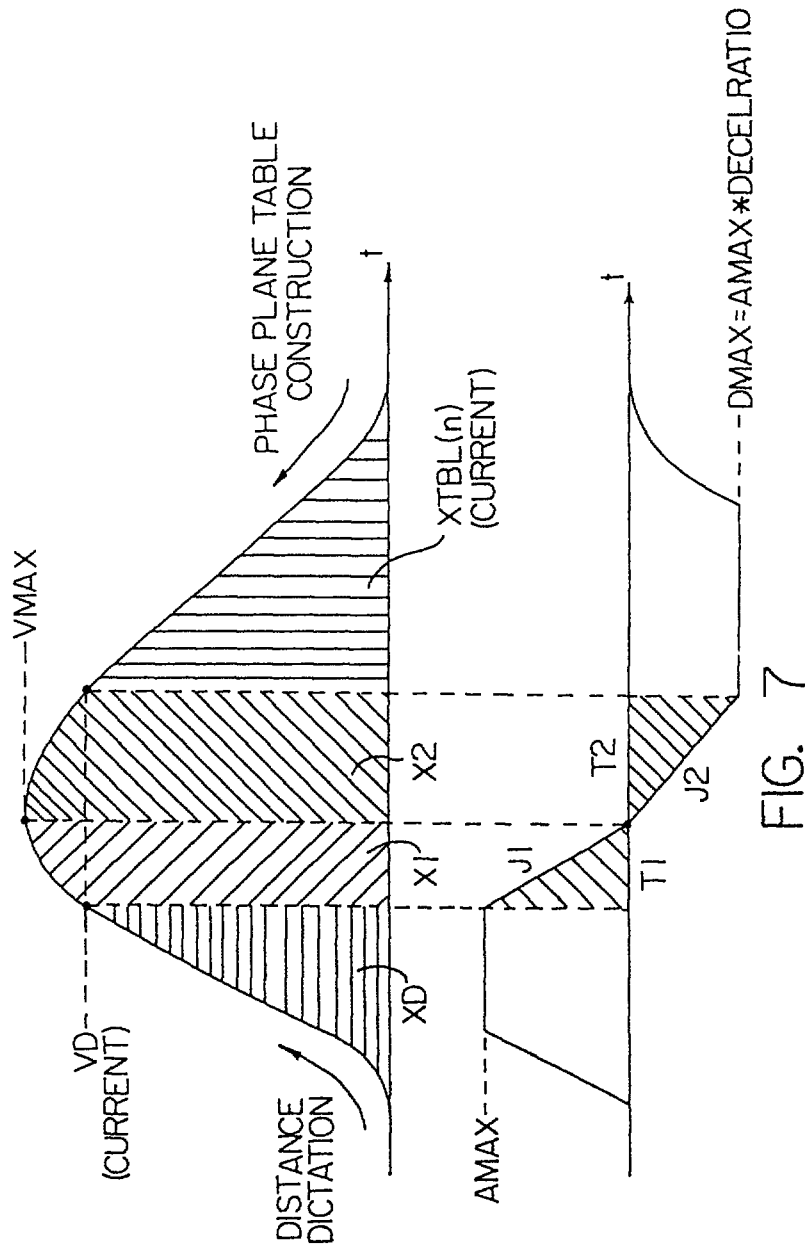
FIG. 6

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ELEVATOR SPEED DICTATION SYSTEM

15/2/99

The present invention relates to elevator systems and in particular to elevator velocity control. Still more precise, the present invention is related to a method for controlling the acceleration and deceleration of an elevator in an elevator speed dictation system.

The need to control the velocity of an elevator is well known. Reference is made, for example, to Document US-A-4,751,984 of Walter L. Williams, Donald G. McPherson & Arnold Mendelsohn entitled "Dynamically Generated Adaptive Elevator Velocity Profile" issued June 21, 1988, as well as to the art cited therein.

As noted in the document US-A-4, 751, 984, automatic elevator operation requires the control of elevator velocity with respect to zero or stop, at the beginning and the end of a trip, to speeds therebetween, which minimize trip time while maintaining comfort levels and other constraints. The time change in velocity for a complete trip is termed a "velocity profile." Automatic elevator control further requires control of the distance travelled during a trip in order to accomplish a precision stop at the destination floor.

Certain velocity profile generation strategies may lead to control instabilities. A common strategy is to use a phase-plane control for precision stopping, wherein dictated velocity is a function of the distance to go to the landing. As the distance-to-go approaches zero, the slope of the velocity/distance curve approaches infinity (∞). Using linear control theory, it can be shown that the slope of the phase-plane curve represents the position error gain for phase-plane control and is proportional to position loop bandwidth. For the speed

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Date: 15 FEB 1999

control loop to track the dictated velocity profile with stability, its bandwidth must be greater by a significant factor than the bandwidth of the position control loop.

One strategy for reducing the required bandwidth is to limit the slope of the phase-plane velocity versus position profile (position error gain) to a maximum value, such that the position loop bandwidth is sufficiently lower than the velocity loop bandwidth.

Generally, the torque producing capability of elevator motors may vary with speed due to motor current, voltage, and/or power limitations. If the drive is not capable of maintaining the acceleration limit under all conditions due to these torque limits, some means of reducing the acceleration (and hence torque) in the corresponding portions of the velocity profile must be provided without compromising operation of the drive at its limit or complicating the profile generation more than necessary.

To avoid, inter alia, these problems, in document US-A-4, 751, 984 each segment of the velocity profile was generated at one of the limits constraining the system; viz., at maximum jerk, maximum acceleration, maximum velocity, maximum position or loop gain, or maximum motor torque. The acceleration portion of the velocity profile preferably was generated in an open loop manner, beginning with constant (maximum) jerk, transitioning to constant (maximum) acceleration after an acceleration limit is attained, and jerking out (negative jerk) at a constant rate to maximum (contract) velocity when the maximum velocity is nearly attained. However, although US-A-4, 751, 984 represents a very substantial advance in the art, it also was subject to improvement, to which the present invention is directed. The disclosure of the document US-A-4, 751, 984 is incorporated herein by reference.

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From document US-A-4,130,184 an elevator speed control system and a method implemented therein has come to be known. During the acceleration of an elevator cab, frequency modulated clock pulses are counted up by a first counter to generate the command speed pattern. The second counter similarly generates second speed pattern identical in shape to and delayed a predetermined time relative to the command speed pattern. A random access memory successively stores theoretical distances of movement of the car due to the command speed pattern suitably corrected and the second speed pattern as a distance-to-speed function. When and after both patterns first equal each other, a command deceleration pattern is generated to follow objectives of the distance-to-speed function. Once the command speed again equals the objective, the intact distance-to-speed function is used as a command deceleration pattern concerning residual distances to stop floor.

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Therefore, it is an object of the present invention to produce a minimum-time velocity/acceleration profile, subject to the following constraints:

- contract speed(s) (as in US-A-4,751,984);
- ride comfort constraints; i.e., acceleration and jerk limits (as in US-A-4,751,984);
- drive torque and power limits (following to some degree US-A-4,751,984); and
- compatibility with the drive system.

In the invention, at a speed close to the base speed of the motor, acceleration reduction preferably is used to keep power requirements well bounded without significantly compromising flight time. This is a form of acceleration profile adaptation based on speed.

Another type of adaptation also may be used. The acceleration and jerk limits for the profile may be adjusted in accordance with available torque. The torque requirements may be determined from the load weighing signal, which gives the load in the cab. The acceleration and jerk limits for the profile can then be adjusted accordingly.

Thus, the profile generator can be made adaptive by presetting the acceleration and jerk limits based on the load in the elevator cab. This can be done by a simple computation based on the load weight made at the beginning of a run. This could be done to permit the use of a smaller than usual drive system, if so desired.

The dictation system of the present invention is capable of generating for output high-quality velocity and acceleration signals. It is advantageous because it is highly structured in design, tolerant of significant computational errors, and is easily modified to handle unusual situations.

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In addition, like US-A-4, 751, 984, the velocity-profile generation approach of the present invention preferably:

- provides for precision stopping at the destination floor and re-leveling;

- complies with the code required door zone and other terminal landing speed limits; and

- accommodates short runs where the contract speed is not reached, as well as very short runs where the "stop control command" (SCC) is reached before the velocity "VBASE" (described more fully below) is reached.

These objects are solved according to the invention by a method of controlling the acceleration and deceleration of an elevator in an elevator speed dictation system according to the features set out in patent claim 1. Dependent claims 2 to 7 exhibit further improvements of the subject-matter of independent patent claim 1.

As part of the improvement to the approach of US-A-4, 751, 984, each segment of the velocity profile likewise is generated at one of the limits which constrain the system; viz., at maximum jerk, maximum acceleration, maximum velocity, maximum position or loop gain, or maximum motor torque. The acceleration portion of the velocity profile preferably is generated in an open loop manner, beginning with constant (maximum) jerk, transitioning to constant (maximum) acceleration after an acceleration limit is attained, and jerking out (negative jerk) at a constant rate to maximum (contract) velocity when the maximum velocity is nearly attained.

The invention may be practiced in a wide variety of elevator applications utilizing known technology, in the light of the teachings of the invention, which are discussed in detail hereafter.

Some of the technological advances achieved and/or followed in the preferred embodiment of the present invention are outlined below.

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1. The velocity is stored in a table as a function of distance gone during acceleration. This table can be used in reverse to find dictation as a function of distance to go during deceleration. The new profile generator explicitly builds the velocity table

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Date: 15 FEB 1960

from DISTTG. In the new profile generator the distance error is not entered in terms of drive tracking delay and velocity. Instead, the actual, MEASURED, distance tracking error is used. The measurement is accomplished by using numerical integration of dictated velocity to find distance dictated. The

DISTANCE GONE = LENGTH OF RUN - DISTTG, and
DISTANCE DICTATED - DISTANCE GONE = DISTANCE
TRACKING ERROR.

The stop control command (SCC) is issued when the following condition is true:

STOPPING DIST. $\geq$ DISTTG - DIST. ERROR -
(2 * VEL * DELTAT)

STOPPING DIST. is computed; DISTTG (distance to go) comes from a position transducer; DIST. ERROR is also measured; and the last term accounts for two cycles of delay in the processor system. VEL is dictated velocity and DELTAT is the processor cycle time (10-40 ms is typical).

5. The stop control command as defined in "4" usually cannot be issued perfectly. The distance range applicable to the velocity and acceleration tables will not match the distance to go. This problem becomes especially severe when the elevator is to be decelerated with look-ahead-distance-to-go (LADTG) rather than DISTTG as the independent variable. The problem is solved in the new profile generator by the introduction of a MULTIPLIER. This multiplier is a scaling factor that acts on the LADTG to make it equal to the distance range for the velocity and acceleration tables. Usually the MULTIPLIER is a number very close to one (1.0) for long runs. It may deviate significantly from one (1.0) for very short runs because of numerical errors. The MULTIPLIER assures that numerical errors, timing delays, etc., will not cause bizarre phase plane trajectories. The phase plane-control in the profile generator

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is self-correcting and robust because of the MULTIPLIER.

6. The look-ahead-distance-to-go (LADTG) is made adaptive in the new profile generator. It is not used for runs of less than 1000 mm (pure DISTTG is used). Further, as the end of a run is approached, LADTG has a "washout" term which is a function of DISTTG. As DISTTG approaches zero, a multiplier acts on the velocity dependent portion of LADTG to make that term less and less significant. Should the control overshoot and the DISTTG go negative, phase plane control reverts to pure DISTTG, rather than LADTG as the independent variable.

7. The profile design is modular, structured, and deterministic. Acceleration, jerk, and distance constraints permitting, it is capable of being altered after a run has begun. The modular design makes design modifications relatively easy. Maintenance of the code and teaching of the design to new engineers is not complicated.

8. The profile generator can be made adaptive by presetting the acceleration and jerk limits based on the load in the elevator cab. This is done by a simple computation based on load weight made at the beginning of a run. This could be done to permit use of a smaller than usual drive system. Working of examples indicates that significant cost savings are possible with little degradation in overall service (traffic flow).

Other features and advantages will be apparent from the specification and claims and from the accompanying drawings, which illustrate two exemplary embodiments of the invention.

Figure 1 is a simplified, block diagram of an exemplary embodiment of the elevator speed dictation system related to the present invention.

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Figure 2 is a graph of the velocity profile of the invention for an exemplary long run of an elevator car in accordance with the exemplary principles of the present invention. (It is noted that the numerical information on the lower, right side of the figure refers to the data values of the traces at the vertical cursor line located to the left side of the graphed, displayed traces; the same being true of Figs. 3-6.)

Figure 3 is a flow chart showing the transitions between the regions of the velocity profile of Figure 2, as well as of the velocity profiles of Figures 4-6, with Regions 0 (zero speed) and 1 (low level phase plane) not being illustrated for simplicity purposes in the velocity profiles.

Figure 4 is a graph of the velocity profile of the invention for an exemplary "Intermediate II" profile of the elevator car, in which the Intermediate II profile illustrates the situation wherein a transition to Region 5 occurs after a Stop Control Command (SCC).

Figure 5 is a graph of the velocity profile of the invention for an exemplary "Intermediate I" profile of the elevator car, in which the Intermediate I profile illustrates the situation wherein there is a transition from Region 3 to Region 5.

Figure 6 is a graph of the velocity profile of the invention for an exemplary short run of the elevator car.

Figure 7 is a comparative graph of exemplary velocity and acceleration curves used in the invention to find the stopping distance.

Best Modes for Carrying Out the Invention

As noted in US-A-4,751, 984, in order to provide rapid, controlled and smooth motion control in an elevator, a velocity profile is generated which observes constraints regarding jerk, acceleration and equipment

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Claims

1. In an elevator speed dictation system, a method for controlling the acceleration and deceleration of an elevator in order to translocate the elevator from a predetermined starting location
- 10 to a predetermined ending location, said method comprising the steps of:
- a) integrating a predetermined jerk rate to obtain a dictated acceleration value (40);
- b) integrating said dictated acceleration value (40) over time to
- 15 obtain a dictated velocity value (20), said dictated velocity value (20) for use by the speed dictation system for causing the elevator to translocate from the predetermined starting location towards the predetermined ending location;
- c) integrating said dictated velocity value to obtain a dictated position value;
- 20 characterized by
- d) determining distance to go (30) based on the distance between the position of the elevator and the predetermined ending location;
- e) determining distance gone based on the distance between the
- 25 position of the elevator and the starting location;
- f) determining distance error based on said dictated position value and said distance gone;
- g) determining stopping distance required to stop the elevator
- 30 based on said dictated velocity value and said dictated acceleration value;
- h) determining compensated distance to go based on said distance to go minus said distance error minus a predetermined value based on system delays;
- 35 i) repeating steps (a) through (h) over time until said stopping distance is at least equal to said compensated distance to go.

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2. In an elevator speed dictation system, the method of claim 1 further comprising the steps of:
- a) determining, for each of said dictated velocity values (20); a table velocity value based on said dictated velocity value (20);
 - 5 b) determining, for each of said dictated velocity values (20), a table position value and a table acceleration value based on said dictated acceleration value (40); and
 - c) storing said velocity values (10), said table position values and said table acceleration values for use by the speed dictation system for decelerating the elevator.
- 10
3. In an elevator speed dictation system, the method of claim 2, wherein said step of determining a table position value comprises the steps of:
- 15 a) determining a maximum velocity value corresponding to a dictated acceleration value;
 - b) comparing said maximum velocity value to said dictated velocity value; and
 - c) calculating said table position value corresponding to said dictated velocity value based on said comparison.
- 20
4. In an elevator speed dictation system, the method of claim 2 or 3, wherein said step of determining a table acceleration value comprises the steps of:
- 25 a) determining a maximum velocity value corresponding to a dictated acceleration value;
 - b) comparing said maximum velocity value to said dictated velocity value; and
 - c) calculating said table acceleration value corresponding to said dictated velocity value based on said comparison.
- 30
5. In an elevator speed dictation system, the method of claim 2, 3, or 4, wherein the step of decelerating the elevator comprises the steps of:
- 35 a) determining the distance to go to (50) the predetermined ending location when the elevator commences said deceleration;

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- 5 b) comparing said commence-deceleration distance to go with the
 most recently stored table position value;
 c) determining a scaling factor based on said comparison;
 d) reading at least a portion of said stored values of table velocity
 and table acceleration from the table as a function of said table
 position value;
 e) interpolating said read values of table velocity and table accele-
 ration based on said scaling factor;
10 f) dictating a velocity value (20) and an acceleration value (40) to
 the elevator based on said interpolated velocity value and said
 interpolated acceleration value, respectively.
- 15 6. In an elevator speed dictation system, the method of claim 2, 3, or
 4, wherein the step of decelerating the elevator comprises the steps
 of:
 a) determining the distance to go to (50) the predetermined ending
 location when the elevator commences said deceleration;
 b) comparing said commence-deceleration distance to go (50) with
 the most recently stored table position value;
20 c) determining a multiplication factor based on said comparison;
 d) determining a compensation factor based on system delays and
 a predetermined washout factor;
 e) determining look-ahead distance to go based on said distance to
 go, said compensation factor and said multiplication factor;
25 f) reading at least a portion of said stored values of table velocity
 and table acceleration from the table;
 g) interpolating said read values of table velocity and table accele-
 ration based on said look-ahead distance to go;
 h) dictating a velocity value and an acceleration value to the eleva-
30 tor based on said interpolated velocity value and said interpola-
 ted acceleration value, respectively.
- 35 7. In an elevator speed dictation system, the method of claim 6,
 wherein said washout factor is a function of distance to go
 (50).

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Date: 15 FEB 1990

Abstract

ELEVATOR SPEED DICTATION SYSTEM

An elevator speed dictation system for controlling the elevator velocity from zero to a maximum velocity and back to zero, illustrated in functional block form in Fig. 1. Velocity profiles over eight regions (Regions 0-7) are provided for zero speed (0), low level phase plane (1), constant jerk to prescribed acceleration (2), prescribed acceleration (3), constant jerk down to constant velocity (4), jerk level after generation of Stop Control Command (SCC; 5), constant speed (6), and phase plane (7), respectively. Velocity profiles for Regions 0-7, including traces of velocity (10), velocity dictated (20), acceleration (30), dictated acceleration (40) and distance to go (50) versus time are graphically illustrated in Fig. 2 & Figs. 4-6 for a long elevator car run, Intermediate II (transition to Region 5 occurs after SSC), Intermediate I (transition occurs from Regions 3 to 5), and a short elevator car run, respectively; while Fig. 7 illustrate velocity and acceleration curves used to find the stopping distance. Fig. 3 provides a flow chart for the transitions between the various regions (0-7) of the profiles.

Figure 1

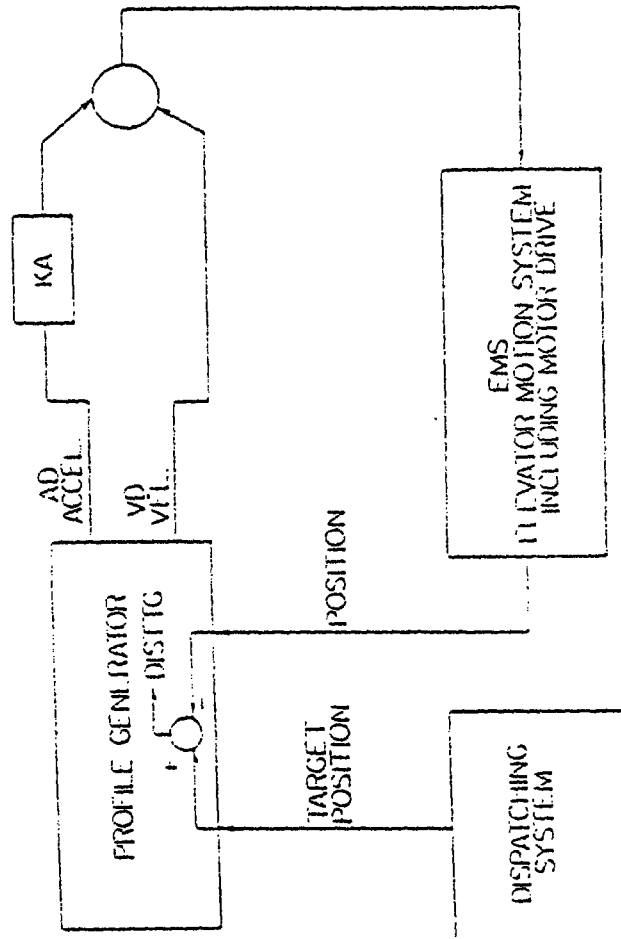
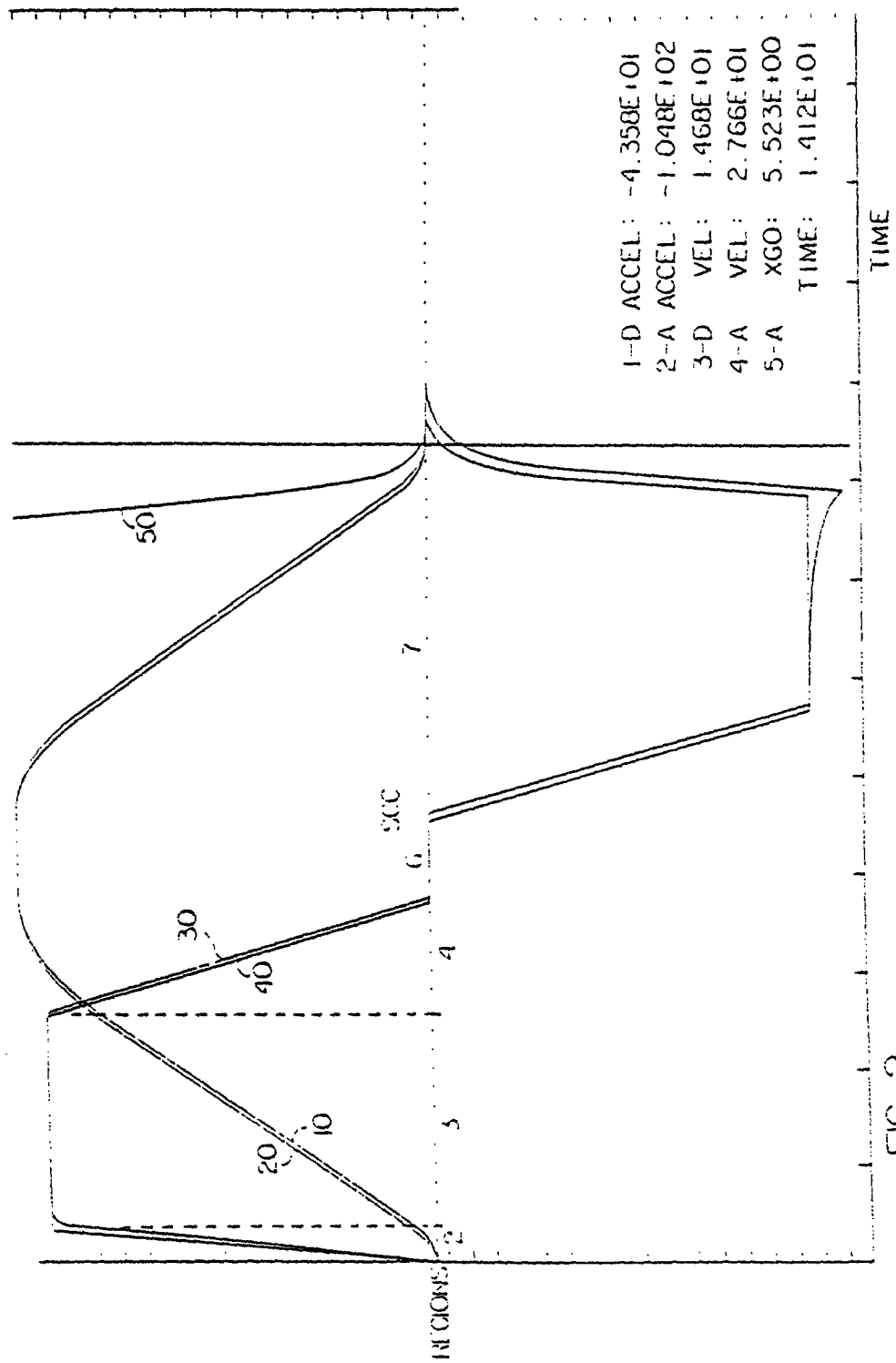


FIG. 1

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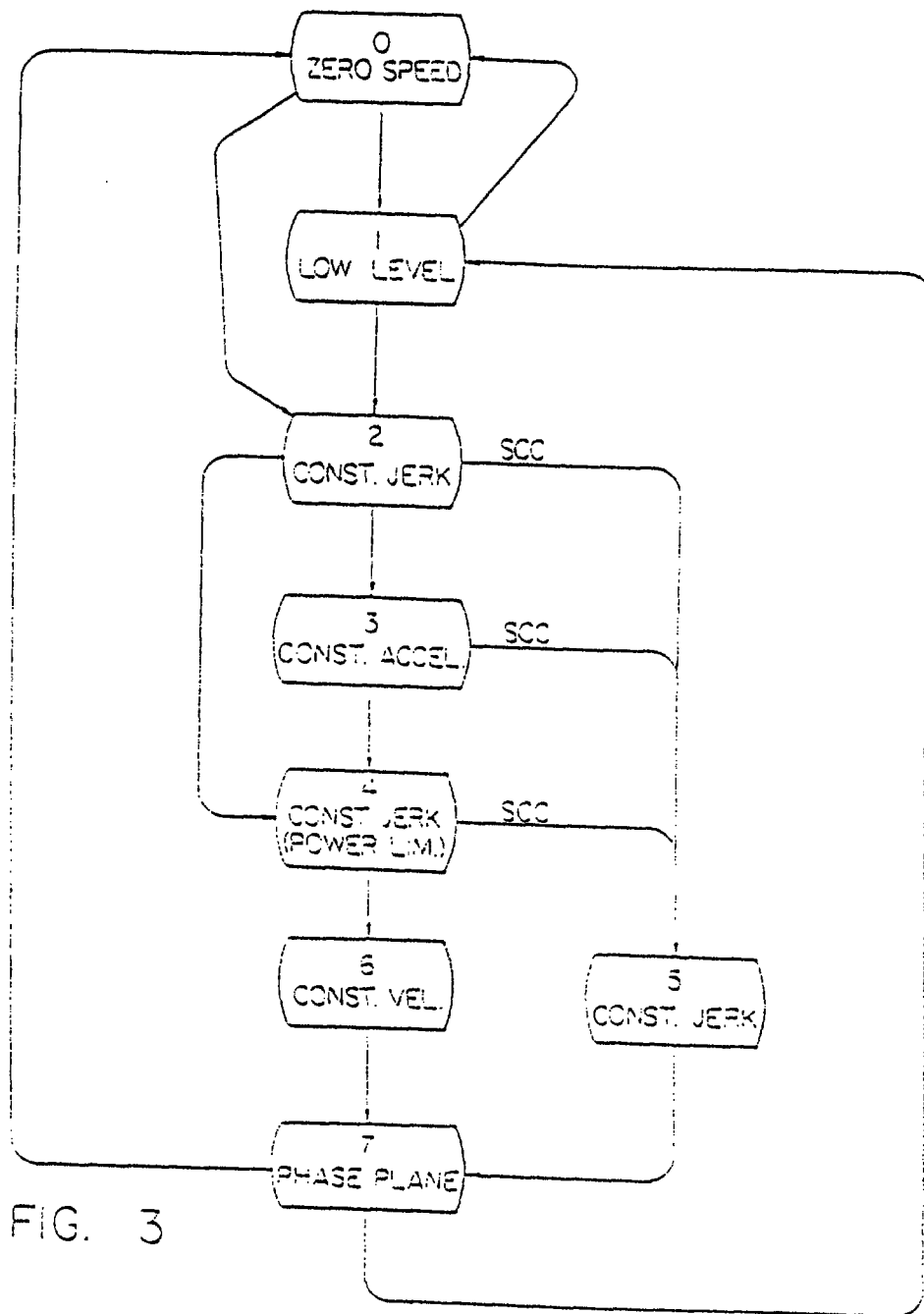


FIG. 3

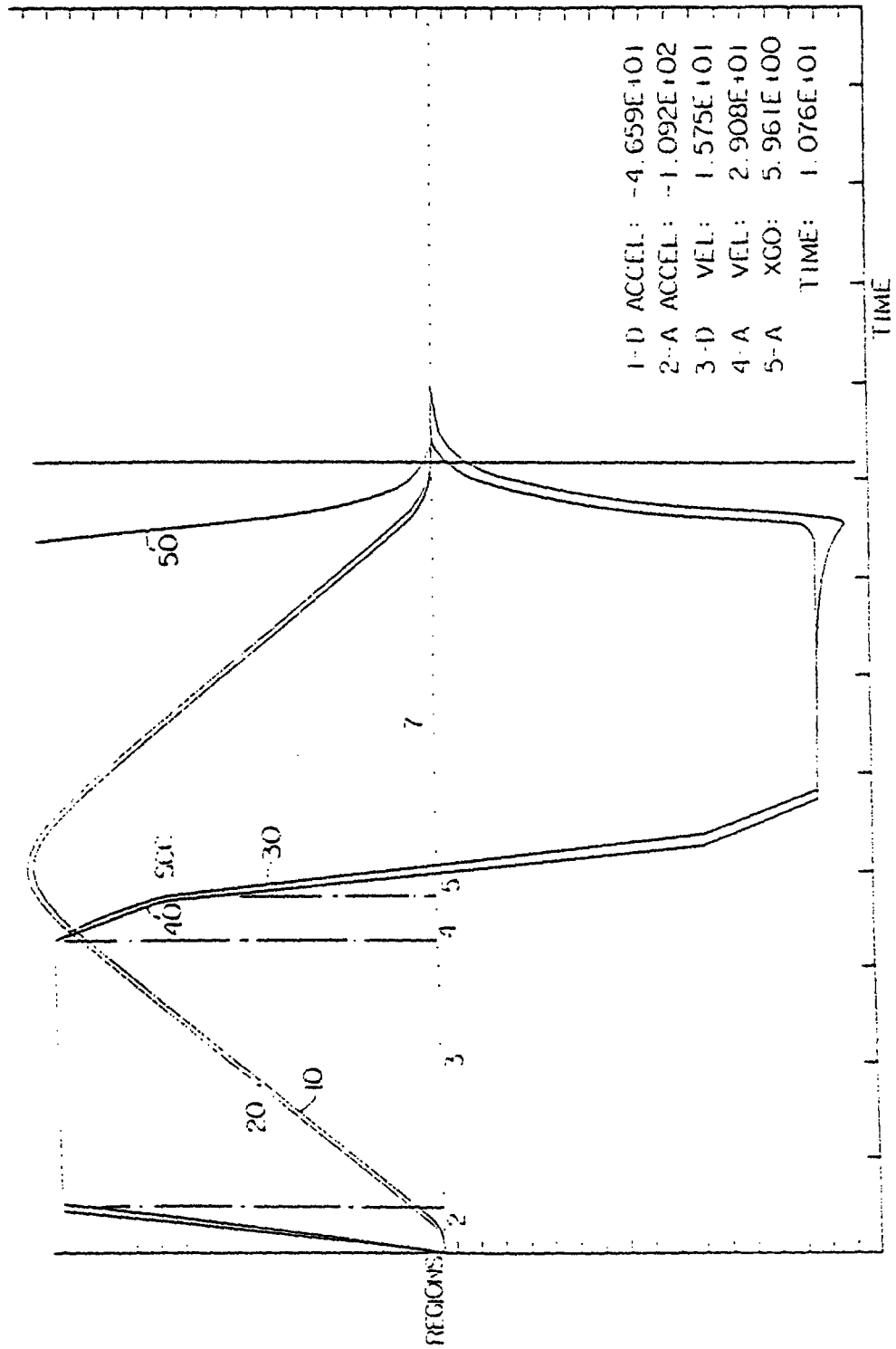
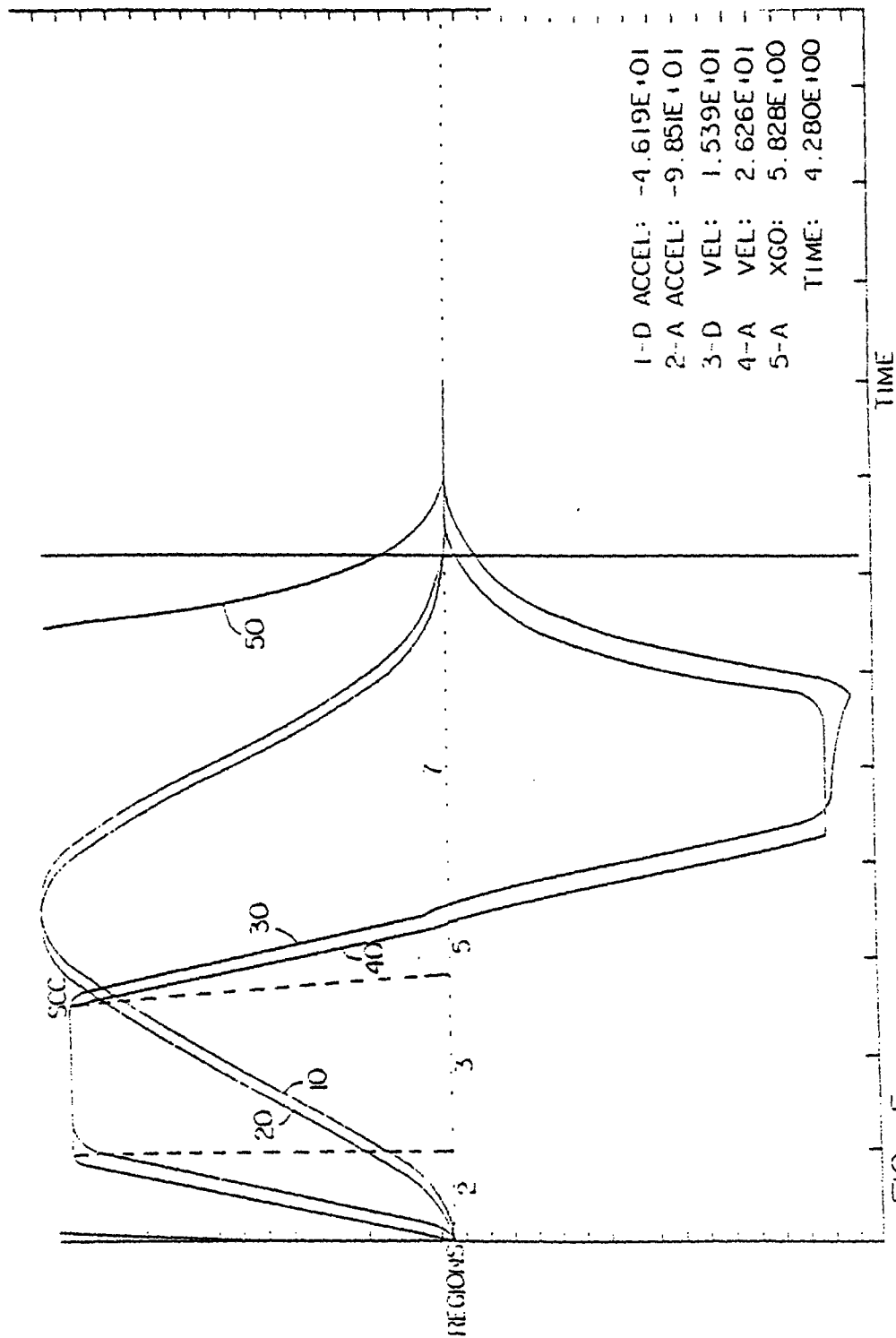


FIG. 4

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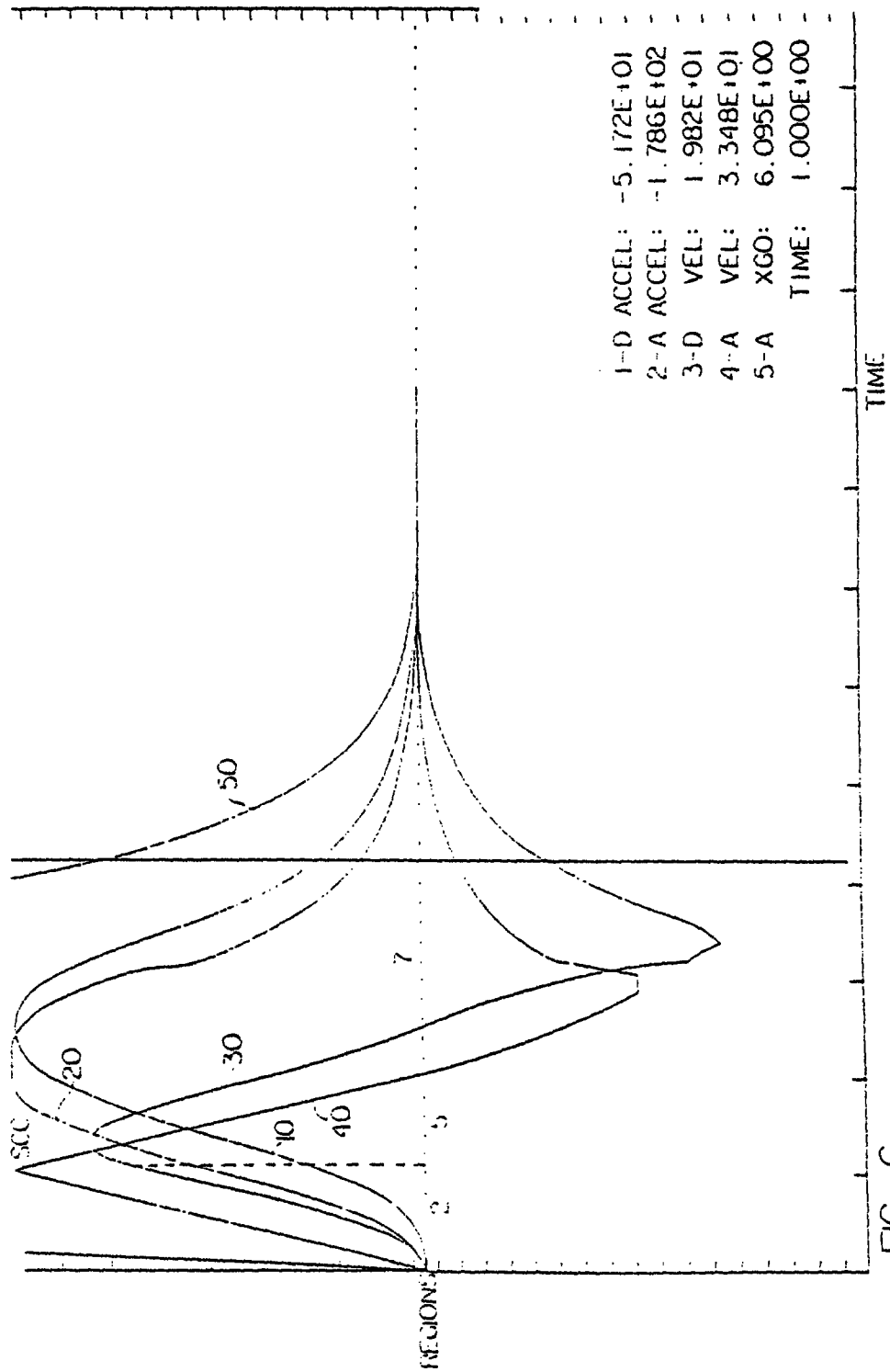
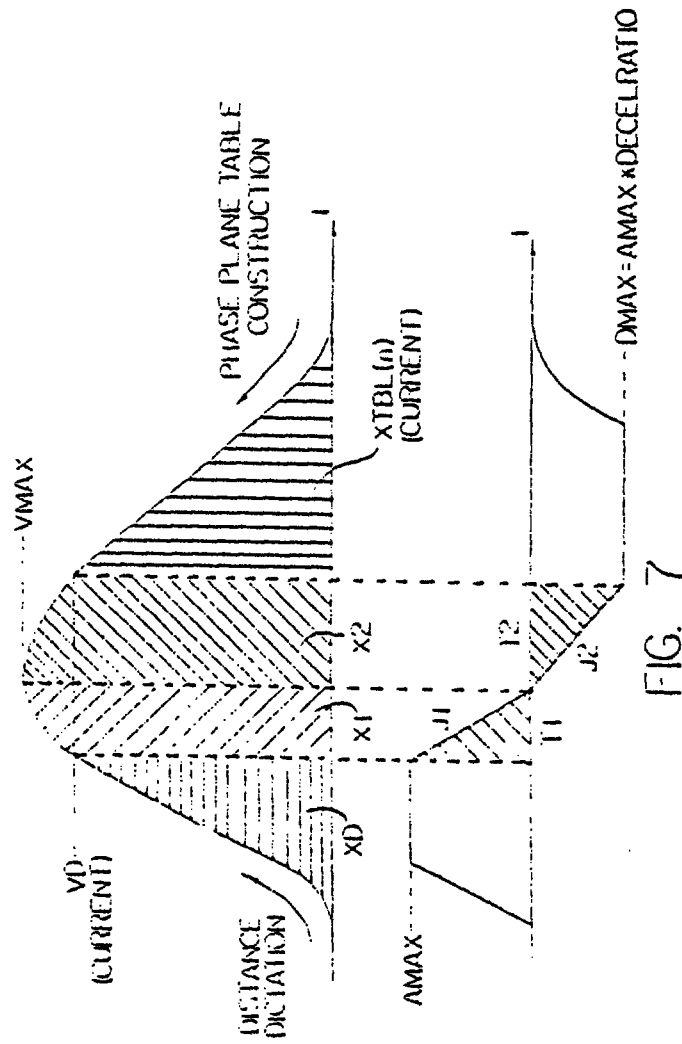


FIG. 6

This is the replacement sheet

Date: 15 FEB 1999



This is the replacement sheet

Date: 15 FEB 1999