Active Parallel Redundancy for Electronic Integrator-Type Control Circuits

A new circuit extends the concept of redundant feedback control from type-0 to type-1 control systems. The inactive channels are slaves to the active channel; if the latter fails, it is rejected and a slave channel is activated.

High reliability and the elimination of single-component catastrophic failure are important requirements in many closed-loop control systems. This redundancy problem is especially acute in systems incorporating electronic integrators. Earlier redundancy attempts included either deleting the integral requirement or using a single integrator with parallel rate stages. The existence of finite static and infinite ramp errors greatly reduced the applicability of the first method; and the use of a single integrator, in the second method, effectively retained a component whose failure would result in complete loss of closed-loop control.

In the circuit developed (see fig.), the integrator outputs are compared by a median-selecting logic circuit providing redundancy: Schematic.
gate (diodes D1 through D9). The gate output, \( e_m = \text{median} (e_1, e_2, e_3) \), is fed back and compared with each individual channel where an error is developed. If the error exceeds the prescribed value

\[
/(\theta_m - \theta_i)/ > \Delta
\]
determined by error-amplifier gain and threshold diode drops, the inactive channels are made slaves to the selected median channel. Inherent drifts of the open-loop inactive integrators is eliminated and, if the selected channel fails, one of the inactive channels is activated. Transfer is automatic, with no substantial transient.

Consider, for example, the case where \( e_1 > e_2 > e_3 \). Diode gate \((D_1, D_2)\) compares \( e_1 \) and selects the maximum; i.e., \( e_1 \). Similarly, diode gate \((D_4, D_5)\) compares \( e_1 \) and \( e_2 \) and selects \( e_2 \), and diode gate \((D_7, D_9)\) selects \( e_3 \), given that \( e_1 > e_3 \). Diode gate \((D_1, D_5, D_8)\) compares the outputs of gates \((D_1, D_2)\), \((D_4, D_5)\), and \((D_7, D_8)\), and selects the minimum output. For this case, \( e < e_1 \), and \( e_2 \) is selected as the desired output \( e_m \), the median of \( e_1, e_2, e_3 \). The output signal \( e_m \) (i.e., \( e_2 \) in this case) is then fed back to differential amplifiers and compared with the individual integrator outputs. For integrator \( A_1 \), the difference between \( e_1 \) and \( e_m \) is generated by \( A_4 \). If this difference exceeded a pre-established threshold, determined by diodes \((D_{10}, D_{11})\) and the differential amplifier gain, integrator \( A_1 \) would be slaved, by the amount of the error, to the output \( e_m \). Similarly, integrator \( A_3 \) would be slaved by the difference between \( e_m \) and \( e_3 \). Since, however, no error exists between \( e_2 \) and \( e_m \) for the example given, no slaving signal is generated by amplifier \( A_5 \), and \( A_2 \) operates as an integrator.

The parameters of the electronic components are not important in this application, because arbitrary values may be selected and the system will correct any mismatch.

**Note:**

Requests for further information may be directed to:

Technology Utilization Officer  
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No patent action is contemplated by AEC or NASA.

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