THEORY OF GAS-EXCHANGE UNITS IN ARTIFICIAL HEART APPARATUSES: SOME PROBLEMS.

COMMUNICATION II. SOME ASPECTS OF THE CONTROL OF THE OPERATION OF FOAM-FILM TYPE OXYGENATORS DETERMINING THEIR PRIMING VOLUME

E. E. Balabin, V. S. Kasulin, and N. A. Super

UDC 616.12-78

It was shown in our preceding communication that the volume of primary filling \( V_2 \) could be expressed in the form

\[ V_2 = v_1 + v_2 + v_3 + v_4, \]  

(1)

where \( v_1 \) is the volume of blood required for renewal of the structure of the foam column, \( v_2 \) is the volume determined by the sensitivity of the blood level-data transmitter, \( v_3 \) is the volume determined by the time characteristic of the tripping device, and \( v_4 \) is the volume of blood determined by the inertia characteristic of the pumping system.

The special automatic blood level-tracking device and the noncontact cutout in the artificial heart apparatus reduce \( v_2 \) and \( v_3 \) to minimal volumes of blood, as the time required for recognition of the danger signal demanding that the perfusion be stopped, and the cutout delay are extremely short, and are only of theoretical significance.

Examination of the volume \( v_4 \) seemed to us to be of the greatest importance. Its value is determined by the time required for complete arrest of the extracorporeal system from the time the cutout operates.

In the AIK apparatuses (AIK-63, AIK-RP-64, AIK-RP-3, etc.), in which the drive is electromechanical, this time depends on the load, the inertia of moving parts, and their initial speed of movement. If the artificial heart apparatus is activated by an electromotor through a reduction gear, let the moment of the inertia of all the moving parts be \( I \), the moment of the load on the electromotor be \( M_1 \), and the initial speed of rotation of the motor shaft \( \omega_0 \).

In simplified form (friction is disregarded), the equation for movement in the system is:

\[ M_1 = -J \frac{d\omega}{dt}. \]  

(2)

Solving this equation, we obtain:

\[ \omega = -\frac{M_1}{I} t + C, \]  

(3)

where \( C \) is the integration constant, found from the initial conditions \( (\omega = \omega_0 \text{ when } t = 0) \). Thus, \( C = \omega_0 \).

Finally,

\[ \omega = \omega_0 - \frac{M_1}{I} t. \]  

(4)
The time \( t \) can be determined from the terminal conditions with \( \omega = 0 \).

\[
\frac{M_1}{J} \cdot t = \omega_0,
\]

whence

\[
t = \frac{\omega_0 t}{M_1}.
\]

As the pump of the apparatus makes \( n \) strokes per minute,

\[
n = \frac{\omega}{i},
\]

where \( i \) is the transmission number for the mechanical drive. If the output of the apparatus \( Q = q \cdot n \), where \( q \) is the stroke volume, then output during the time required for stopping will vary directly with the speed of rotation \( \omega \) or the stroke rate \( n \).

The change in output in time can be represented by the equation:

\[
Q_i = q \cdot n_i,
\]

where

\[
n_i = \frac{\omega}{i} = \frac{\omega_0}{i} - \frac{M_1}{I} \cdot t.
\]

Also, as \( Q_i = \frac{dq}{dt} \), then, substituting this in the equation, we obtain:

\[
v_i = \frac{1}{2} \left( \omega_0 - \frac{M_1}{I} \cdot t \right) dt,
\]

and, by integration,

\[
v_i = \frac{q}{i} \omega_0 + C_1 - \frac{M_1 q}{I^2} \cdot \frac{\omega_0^2}{2} + C_2,
\]

where \( C_1 \) and \( C_2 \) are integration constants, determined from the initial conditions with \( t = 0 \) and \( v_i = 0 \). Hence \( C_1 + C_2 = 0 \). Substituting the expression (6) in Eq. (10), we obtain:

\[
v_i = \frac{q \cdot \omega_0^2 \cdot t}{2I M_1^2} \cdot \frac{M_1 q}{i} \omega_0^2 \cdot t^2
\]

or

\[
v_i = \frac{q \cdot \omega_0^2 \cdot t}{2I M_1}
\]

Expression (12) shows that the volume, which diminishes with reduction in the time taken to halt the system, depends primarily on the constructional features of the drive for the artificial heart apparatus, i.e., on the moment of the inertia of all its moving parts (\( D \)), the moment of the load (\( M_1 \)), the initial rotation speed of the electromotor shaft (\( \omega_0 \)), the transmission number (\( i \)), and the stroke volume (\( q \)).

The moment of a special braking device (\( M_b \)) can be added to the moment of the load (\( M_1 \)). We then obtain:

\[
v_i = \frac{q \cdot \omega_0^2 \cdot t}{2I (M_1 + M_b)}
\]

This device will reduce the volume required for primary filling of foam-film type oxygenators, but may complicate the construction of the drive for the artificial heart apparatus, as the brake must only come into operation when the motor itself is slowing down.

197