ABSTRACT: An arrangement for injecting a contrast medium into the heart of vascular system of a patient, in a precisely controlled fashion. The movement of the injecting syringe is driven by a constantly rotating motor, via an electromagnetic coupling. The coupling connects the syringe piston to the drive shaft of the motor so that when the coupling is actuated by current flowing through the coil of the coupling, the syringe is made to respond immediately to such actuation. The speed of the injection of the contrast medium or medical fluid is closely regulated through the action of the coupling and the driving motor. Indicating means are provided whereby the amount of fluid retained within the syringe is continuously indicated. When the amount of fluid within the syringe drops below a predetermined level, actuation of the syringe is immediately inhibited. Control circuitry provides a signal when the number of injections that have taken place correspond to a predetermined quantity, and a push-button assures that the injection of the medical fluid cannot take place unless the latter is depressed.
POWER DRIVEN MEDICAL INJECTOR SYRINGE WITH ELECTROMAGNETIC COUPLING MEANS

BACKGROUND OF THE INVENTION

It is well known in the art that for purposes of performing X-ray examination and investigations of the circulatory systems of patients, a fluid in the form of a contrast medium must be injected into the vascular system. The tolerable amounts of fluids which may be injected are limited and are as follows:

The maximum dosage for adults is 1.5 ml./kg. of body weight. For children, the maximum dosage is 2-3 ml./kg. of body weight.

Since a pulsed flow prevails in the circulatory system and in the heart, the injection process must be extremely rapid in order that sufficient concentration of contrast medium is present at a particular location, for diagnostic purposes.

During heart examinations and especially when large volumes of injecting fluids are involved, very severe technical requirements must be adhered to. Thus, the injection speed must be extremely large, the pressure rise must be rapid, the injection must be performed with sharply defined beginning and end points, the injected volume as a function of time must be precisely measured, and the total amount of fluid that has been injected must be closely controlled at any instant.

Recent investigations have shown that during the contraction or evacuation phase of the heart, it is not desirable to inject the contrast medium into the vascular system. Thus, during this period of the contraction phase, the injected contrast medium is simultaneously ejected and becomes thereby useless from the diagnostic point of view, since the information that was to be derived therefrom cannot be realized. Furthermore, due to the reduction in the volume, within the heart, due to the contraction phase, it is dangerous to inject into the heart or the vascular system. Accordingly it is of advantage to inject the fluid intermittently only when the filling phase takes place, corresponding to normal hemodynamic techniques. When this technique is observed whereby the injection of the contrast medium is performed intermittently only during the filling phase of the heart, considerably more information is made available of the heart condition, and with less danger and disturbance to the system of the patient. However, as a result of applying this particular examination technique, a substantially shorter period of time is available for the injection. Accordingly, the injection must be accomplished with a rapid pressure rise, precise regulation of the timing and volumetric parameters of the injection impulse as a function of the electrocardiogram, as well as close programming of the injection apparatus. Conventional injection apparatus for the contrast medium, have an injection piston driven by an electric motor which may be operated as an on-off unit. However, it has been found that such conventional apparatus cannot respond sufficiently rapidly to an electrical signal for controlling the on-off operation of the motor. Furthermore, the conventional apparatus has the disadvantage that a time lag of 0.3 to 0.7 second prevails between the instant that an electrical control signal for operating the motor is transmitted and the instant that the injection piston acquires the necessary designated speed. This disadvantage condition results principally from the fact that in the conventional apparatus the electric motor drives the injection head through a screw mechanism having a longitudinally movable screw spindle. With such design considerable mass is inherently accelerated or decelerated commensurate with the on-off operation of the motor, and this is responsible for the large delays in response. The solution to the problem does not reside in providing a larger motor with greater power capabilities, because such a modification in the design of the apparatus would produce an unmanageable system due to the heavier construction that would be required in all aspects of the design.

In other conventional apparatus for injecting medical fluids, the injection is performed through the action of a pneumatic cylinder operating in conjunction with a control valve. These pneumatic designs derive the air from pressurized storage tanks which will last only for a relatively few operating hours.

At the same time the time lags associated with the motion of the injection piston are even larger than those encountered in the systems using electrical motors.

With these viewpoints in mind, the present invention is of special advantage because it accomplishes the injection motion in a rapid and sharply defined on-off operation.

One object of the present invention is to provide an injection apparatus in which the speed of the injecting piston may be preselected. The present invention provides, moreover, for a continuously moving electric motor which, upon the application of a control signal, drives the sliding mechanism of the injection piston within the prescribed time interval and at the preselected speed. It is also an object of the present invention that upon transmission of the control signal, 90% of the designated speed of the injection system should be attained within 100 msec.

The present invention accomplishes the preceding objects by providing a screw spindle driven as a result of a motor and a nut in mesh with the screw spindle. The screw spindle is supported by a spindle retainer. Between the latter and the nut, resides an electromagnetic coupling controlled by a control signal. The design is such that in one state of operation the spindle retainer is secured to the nut to provide for the desired translational motion of the spindle. In another state of operation translational motion of the spindle is inhibited.

In accordance with another embodiment of the present invention, a hydraulic operating mechanism is connected to the injection piston. A motor driven pump sets into motion a hydraulic fluid against pressure. A volume regulating valve regulates the flow of the fluid through the hydraulic system. In one state of a hydraulic control valve, operated by a control signal, the hydraulic fluid is returned to the intake of the pump via a hydraulic resistance. In the other state of the hydraulic control valve, a differential piston is operated whereby the injection piston is translationally moved in the desired manner.

It is very useful, when possible, to monitor continuously the position of the injection head for the purpose of determining the volume of contrast fluid available. Thus, when the volume of fluid remaining within the syringe drops below a predetermined level, the injection apparatus may be immediately switched off. It is also desirable that any injection phases take place only when a pushbutton is maintained depressed by the responsible physician in charge. In this manner the physician can discontinue the injection operation at any instant by the release of the pushbutton. It is of special significance when the control signal for operating the injection apparatus is regulated as a function of the operation of the heart, by being associated with the electrocardiogram. Thus, operation of the injection apparatus can be inhibited whenever a spike signal appears on the electrocardiogram. In such an arrangement the maximum duration of the injection phase as well as the number of injection impulses may be closely regulated. The volume of contrast medium injected into the patient is, furthermore, also limited. After successful injection of a predetermined volume of contrast medium, a control signal may be transmitted for the purpose of automatically switching on X-ray examination apparatus.

SUMMARY OF THE INVENTION

A medical injection apparatus having a syringe with a movable piston therein for injecting a predetermined quantity of fluid into the vascular system of a patient. The piston of the syringe is moved translationally through the action of a continuously operating motor. The motor as well as the piston of the syringe are driven at a predetermined speed. Intermittent operation of the syringe piston is accomplished through an electromagnetic coupling connecting the piston with the continuously operating motor. A control signal transmitted to the electromagnetic coupling connects or disconnects at will the syringe piston drive from the electric motor. The on-off opera-
tion of the intermittent drive is such that extremely rapid response to the electrical control signal is realized. The time interval during which the injection phase takes place is precisely regulated, as well as the speed of injection. The volume injected into the patient as well as the number of injection impulses are also continuously monitored. Safety devices are included to minimize any danger to the patient as a result of the injection processes.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

**BRIEF DESCRIPTION OF THE DRAWING**

FIG. 1 is an elevational view of the supporting structure of the injection apparatus;

FIG. 2 is a plan view of the injection apparatus of FIG. 1;

FIG. 3 is a functional electrical schematic diagram, and shows the manner in which the action of the injecting syringe is controlled;

FIG. 4 is a timing diagram of the signal flow through the electrical circuits and controlling apparatus in FIG. 3;

FIG. 5 is a cross-sectional elevational view of a screw-operated driving mechanism for securing on-off operation of the syringe; and

FIG. 6 is a functional schematic diagram of a hydraulic system, and shows another embodiment for controlling the action of the syringe hydraulically.

**DESCRIPTION OF THE PREFERRED EMBODIMENTS**

Referring to the drawing and in particular to FIGS. 1 and 2, a moveable carriage A carries a supporting member B for the injection apparatus and its associated control equipment. The syringe is denoted by C. It is actuated by a driving mechanism located within a housing D having an interchangeable supporting arm D1 for the purpose of gripping the syringe. The housing D also contains control and switching mechanisms which have their operating and adjusting members arranged on the operating panel D2. An electronic unit D3 is connected to the housing D and has its operating members on the front panel D3a. By means of the clamping screw B1, all parts secured to the housing D may be rotated about the horizontal axis of FIG. 1, or the vertical axis of FIG. 2. Thus, these parts may be adjusted and positioned in any desired manner. The upright position of the supporting arm D1, shown in FIG. 1, serves for the purpose of removing the air from the syringe C. In this regard, the piston head is set for executing slow filling and injection motions. In order to drive out all air bubbles that may remain in the syringe, it has been found useful to provide a small electrical vibrator C2 at the supporting arm D1, in the vicinity of the syringe C. The principle governing the functional operation of the apparatus of FIGS. 1 and 2 is shown in FIG. 3.

In accordance with FIG. 3, the injection apparatus serves the purpose of injecting a contrast medium into the heart and hence the vascular system of a patient H lying on a table E exposed to X-ray apparatus F. The observation apparatus is denoted by G. In accordance with the arrangement, the functions of the heart of the patient H are continuously monitored by the cardogram I, so that a signal in the form of i appears as in FIG. 4. The signal i is also applied to a commonly known Schmitt trigger circuit J which provides a trigger signal j that has a duration which is at least as long as the duration of the spikes in the signal i. The Schmitt trigger circuit is actuated by the monitoring signal i. On the basis of the manner in which the cardogram apparatus I is connected to the body of the patient, the contraction phase of the heart may also be represented by an electrical signal which, for example, corresponds to the signal j resulting from the trigger circuit J.

A push-button K having two switching contacts K1 and K2 are provided to enable the attending physician to release the injection mechanism and to block it as desired. Thus, when the push-button K is depressed, the injection mechanism becomes operative, whereas it remains in the inoperative state at all other times. The signal resulting from the depression of this push-button K is designated by k in FIGS. 3 and 4. A multivibrator or similar timing circuit L capable of providing a time delay t1 supplies binary signal 1 upon the rise of the trigger signal j. After the elapse of the time interval t1, the binary signal 1 ceases.

The signal 1 is applied to a second timing circuit M which may be set for maximum time t2 for the purposes of determining the maximum duration of a signal m. The circuit M becomes operative when the signal 1 ceases, and becomes inoperative, on the other hand, when the signal 1 rises. This operation of the circuit M is, at the same time, accomplished no later than the elapse of the maximum time interval t2. As a result, the volume of the contrast medium injected, is limited to a quantity below a predetermined maximum. Fundamentally, it is possible to provide that the signal m be directly applied for the purpose of actuating the movement of the syringe piston C1.

A driving mechanism for the syringe is denoted by N and shown schematically in FIG. 3. This driving mechanism includes an electrical motor N1 which is connected to the power supply by means of the switch N11. The speed of rotation of the motor for the purpose of regulating the volume injected, may be adjusted in a fully continuous manner through the potentiometer N12. Speed control means are commercially available for switching control of the electric motor to an exceptionally low speed range. These can be used to fill and empty the syringe for the purpose of removing the air therein. The motor N1 operating at a predetermined speed, drives the actuating mechanism N2 for the injection of piston head C1, with corresponding speed. The magnetic coil N3 serves as the on-off switching mechanism for the motor of the injection head, through means of the control signal o. Concrete examples of the drive N4 operating in conjunction with a continuous rotating motor N5 are given in FIGS. 5 and 6.

In FIG. 3 is also shown a mechanism to which the motion of the injection piston is transmitted by way of a flexible tension member O1 secured to a spring O2. The flexible tension member O2 passes over a volume indicating disk O3 and a volume selecting member O5. The scale and the indicating disk O2 provides an indication, therefore, of the volume of contrast fluid within the syringe. The volume selector O5 is provided with a cam projection O6 which actuates an electrical switch O7. Thus, the battery O8 is maintained in the open state when the volume of fluid within the syringe is below a predetermined limit V1 (FIG. 4). Since the switch O8 is connected in series with the switching coil N3a, the injection motion can take place only when the contents within the syringe are above the predetermined limit V1. In the simplest manner, the gap at P may be bridged so that a positive voltage may be applied to the actuating coil N3a when the switching contact K2 is closed, as well as the switch O5. Thus, by depressing the push-button K the syringe C may be operated until the minimum volume therein is attained.

In accordance with FIG. 3, the bridge P is connected to the output of a logical AND gate Q which has, as one of its input signals, the output of the timing circuit M. The second input R of the gate Q is realized from a register R into which may be inserted a maximum quantity t2 as, for example, five injection impulses. The register is set back by one unit whenever the actuating coil N3a receives a new current impulse o. As soon as the predetermined quantity m has been attained, and the register R is thereby in its zero state, the signal r is switched off so that further releases of injection impulses is not possible.

From the preceding description of FIG. 3, it may be seen that the actuating coil N3a can receive operating current signals o, only under the following conditions:

a) The push-button K must be depressed.
b) No signal 1 must be present, implying that the injection motion is blocked for a predetermined time interval $t_6$ beginning from the instant that the spike on the cardio- graphic i begins to rise.

c) The duration of the injection period cannot exceed the predetermined maximum value $t_6$.

d) The maximum number of impulse signals $r_6$ on the re- gister cannot be exceeded.

e) The minimum residual quantity $v_6$ inserted by way of the residual register $O_6$ must be exceeded.

In order that the speed of injection corresponds to the pre- determined motor speed, the injection flow as well as the injection impulse of fluid volume is limited through the limiting of the duration $t_6$.

Through the use of similar auxiliary equipment, it is possible to derive a signal $O$ which actuates, for example the X-ray appar- atus $G$ or parts thereof, when a predetermined quantity of contrast medium has been injected.

In accordance with FIG. 5, the driving shaft 10 of an electric motor 1 rotateable at a predetermined speed, drives a gear train 13 via the coupling 11. The driven gear of the trouble 12 meshes with the peripheral geared surface of a planetary gear 13. A plurality of planetary spindles 14 are freely mounted within the planetary gear 13 so that they are movable about the central axis of the planetary gear. The circumferential ribs of the planet spindles 14 mesh with a screw thread of a main screw spindle 15 which is coaxial with the gear 13. The plan- etary gear train acts upon the screw spindle 15 in the form of a screw nut, but with lower frictional losses. As long as the main spindle rotates with the same angular speed as the gear 13, no axial displacement takes place with respect to this main spin- dle. Upon braking the rotational motion of the main spindle, an axial displacement of the spindle 15 takes place in the direction indicated by the arrow $P_{15}$. This axial displacement occurs most rapidly for complete blocking of the rotational motion of the main spindle 15, for a predetermined speed of the gear 13.

The main spindle 15 is securely keyed by means of the key 16 to a spindle carrying sleeve 17. The keying arrangement is such that the main spindle 15 is slidable within the sleeve 17 but not rotatable with respect thereto. The spindle supporting sleeve 17 is, as the gear 13, rotatably supported in stationary members 18a and 18b of a housing and coaxial to the main spindle 15.

Through a friction coupling represented by a disk spring 19, the gear 13 is coupled to the flange portion 170 of the spindle supporting sleeve 17. The hub 171 of the spindle supporting sleeve 17 is keyed to the disk 20 of a magnetically actuated coupling including the magnetic coil 200. The keying arrange- ment is such that whereas relative rotation between the key members is inhibited, they may slide axially with respect to each other. When the coil 200 is in the de-energized state shown, the disk 20 rotates with the sleeve 17 which, on the other hand, is driven by the gear 13. When the coil 200 becomes energized, the disk 20 is drawn towards the coil 20 and tends toward the stationary housing portion 18a. As a result, the rotational motion of the disk 20 is inhibited. Beginning from this instant, the spindle retaining assembly 170-171 is stationary, and a corresponding axial motion of the main spindle 15 is forced in the direction of the arrow $P_{15}$. When the current through the coil 200 ceases, the gear 13 rotates against the sleeve 17, through the frictional coupling 19. As a result, the main spindle 15 is rotated with the same speed of the gear 13 and the axial motion of the spindle 15 is in the direction of the arrow $P_{15}$. Subsequently, no time lag prevails with regard to the transfer of motions of the spindle 15 between the rotational motion and the axial sliding, as a result of the current through the coil 200. Through the ar- rangement of the present invention, involving the screw thread drive, a very well defined yes-no transfer device is ob- tained for the spindle sliding motion. Thus, when the current in the coil 200 is switched to a different level, 90% of the corre- sponding motion of the spindle is realized within 0.01 seconds.

A hydraulic embodiment for driving the mechanism whereby the contrast medium is injected, is shown in FIG. 6. This arrangement includes an electrical motor 30 which may be connected to a current supply 32 by means of a switch 31. The motor 30 drives, by means of a coupling 34, a hydraulic pump 35. The latter takes a hydraulic fluid working medium from a storage tank 36 and forces it into a pressure line 37. A safety valve 38 allows the pressurized fluid to return to the storage tank when the pressure in the line 37 exceeds a predetermined value. A three-way regulating valve 40 allows a predetermined volume of fluid to flow in the line 41, as a func- tion of time. Any excess volume of fluid is transferred to the branch line 39. An electromagnetic valve 420 controlled by an electrical coil 42 connects the fluid line 41 with the fluid line 43 leading to a throttle member 44 connected to the return flow line 39. When current is permitted to flow through the coil 42 by means of the closing, for example, a switch K, the fluid line 41 no longer communicates with the fluid line 43 leading to the throttle arrangement 44. Instead the fluid line 41 is, under these conditions, connected to the fluid line 45.

The latter leads to a hydraulic cylinder 47 containing a differen- tial piston 46. The same pressure prevails on the left sur- face of the piston 46 because this side of the piston is fed with fluid from the line 41a. However, the force is greater upon the right surface of the piston 46, and as a result the injection piston $C_1$ of this syringe $C$ is actuated and injects the contrast medium into the patient. Together, may also find a useful applica- tion in other types of medical injection apparatus differing from the types described above.

While the invention has been illustrated and described as embodied in medical injection apparatus, it is not intended to be limited to the details shown, since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adapta- tions should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

We claim:

1. A medical injection apparatus comprising, in combina- tion, a syringe having a movable syringe piston for injecting medical fluid; driving means for driving said piston within said syringe; a continuously operating energy source for operating said driving means at a predetermined speed; an electromagnetically operated coupling connecting said driving means with said energy source upon application of a control signal to said coupling, whereby said syringe piston moves at said predetermined speed immediately upon actuation of said coupling by said control signal, said syringe piston becoming stationary immediately upon the release of said coupling by said control signal; push-button means for transmitting said control signal to said coupling means only when said push-but- ton means is depressed; and delay means for delaying said control signal to said coupling by a predetermined time inter- val.

2. The medical injection apparatus as defined in Claim 1 in- cluding means for regulating the maximum duration of injecting said fluid within said syringe.

3. The medical injection apparatus as defined in Claim 2 in- cluding regulating means for limiting the maximum number of injections to be performed by said syringe.
4. The medical injection apparatus as defined in Claim 3 including signal emitting means for emitting a signal when a predetermined amount of fluid has been injected by said syringe.

5. A medical injection apparatus comprising, in combination, a syringe having a movable syringe piston for injecting medical fluid; driving means for driving said piston within said syringe; a continuously operating energy source for operating continuously said driving means at a predetermined constant speed; actuating means linked to said driving means and continuously driven at said constant speed when in a freely operating state; and an electromagnetically operated coupling connected to said actuating means for changing the speed of said actuating means when engaged by said coupling upon application of a control signal to said coupling, whereby said driving means moves said syringe piston at a predetermined constant speed immediately upon actuation of said coupling by said control signal and change in speed of said actuating means, said syringe piston becoming stationary immediately upon disengagement of said actuating means from said coupling through termination of said control signal, said actuating means returning to said freely operating state upon termination of said control signal.

6. The medical injection apparatus as defined in Claim 5 wherein said driving means comprises a threaded spindle coupled to said piston for moving the same, said actuating means comprising a threaded sleeve retaining said spindle and rotatable with respect thereto; and a rotatable nut whereby said spindle sleeve is connected to said nut in one state of said coupling, and motion of said sleeve is inhibited in the other state of said coupling.

7. The medical injection apparatus as defined in Claim 5 including indicating means for continuously indicating the position of said syringe piston for providing an indication of the amount of medical fluid within said syringe.

8. The medical injection apparatus as defined in Claim 7 including volume selecting means for selecting the minimum volume of fluid to be contained within said syringe, whereby said syringe piston is inhibited from moving when the medical fluid within said syringe is below the preselected volume.

9. The medical injection apparatus as defined in Claim 5 including push-button means for transmitting said control signal to said coupling means only when said push-button means is depressed.

10. A medical injection apparatus comprising, in combination, a syringe having a movable syringe piston for injecting medical fluid; driving means for driving said piston within said syringe; a continuously operating energy source for operating said driving means at a predetermined speed; an electromagnetically operated coupling connecting said driving means with said energy source upon application of a control signal to said coupling, whereby said syringe piston moves at said predetermined speed immediately upon actuation of said coupling by said control signal, said syringe piston becoming stationary immediately upon the release of said coupling by said control signal, said driving means comprising: a hydraulic cylinder and piston for moving said syringe piston at a predetermined speed; a motor driven hydraulic pump for forcing fluid into said hydraulic cylinder; a fluid regulating means for regulating the amount of fluid admitted to said hydraulic cylinder; a hydraulic control valve for diverting in one state the fluid from said cylinder and passing another state said fluid to said cylinder for moving said syringe piston to inject medical fluid; and hydraulic throttle means connected to said hydraulic control valve for receiving the fluid diverted from said hydraulic cylinder and transferring the diverted fluid to the intake of said pump, whereby said hydraulic piston moves said syringe piston when said hydraulic control valve passes fluid into said hydraulic cylinder.