

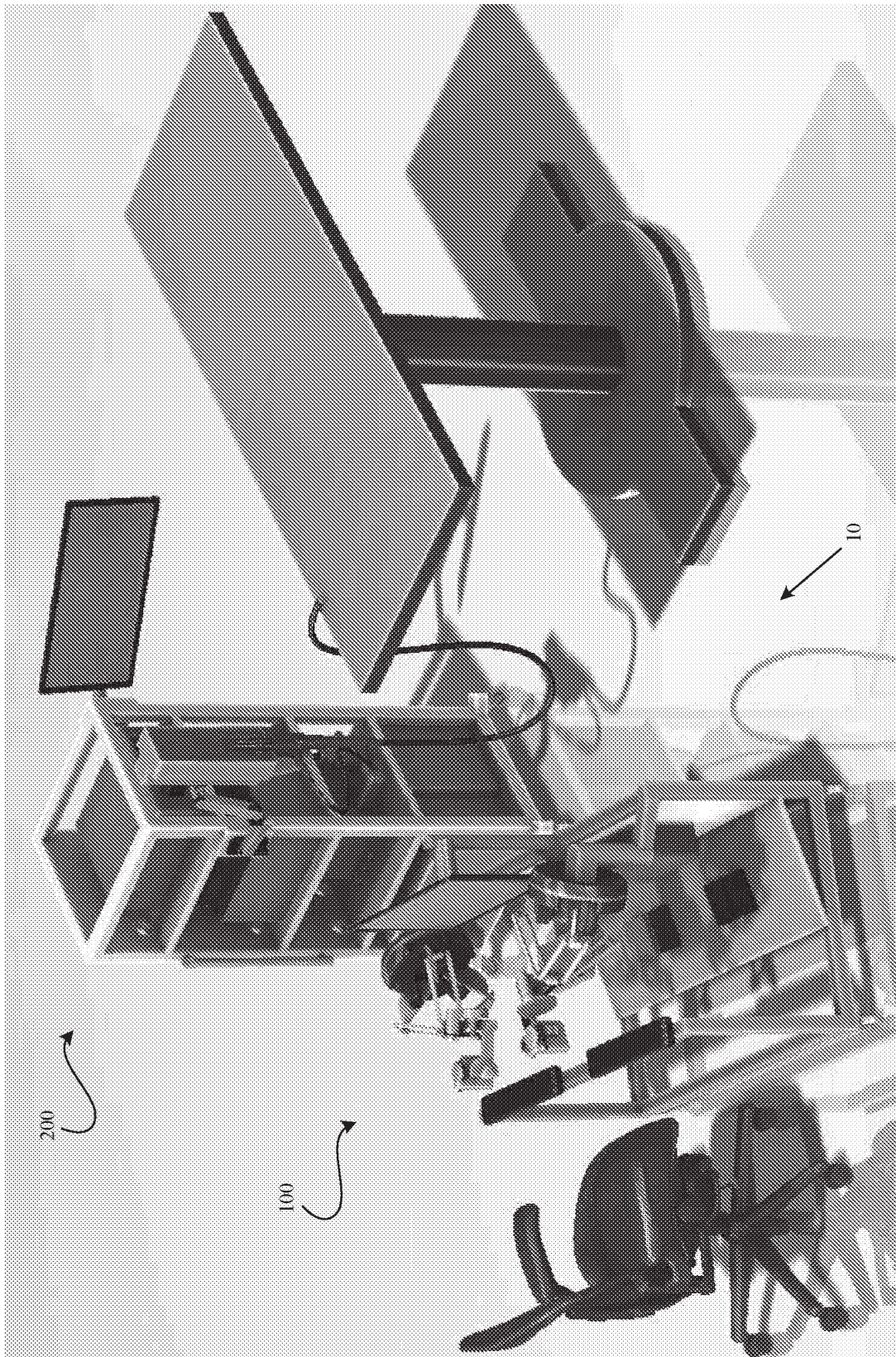


FIG. 1A

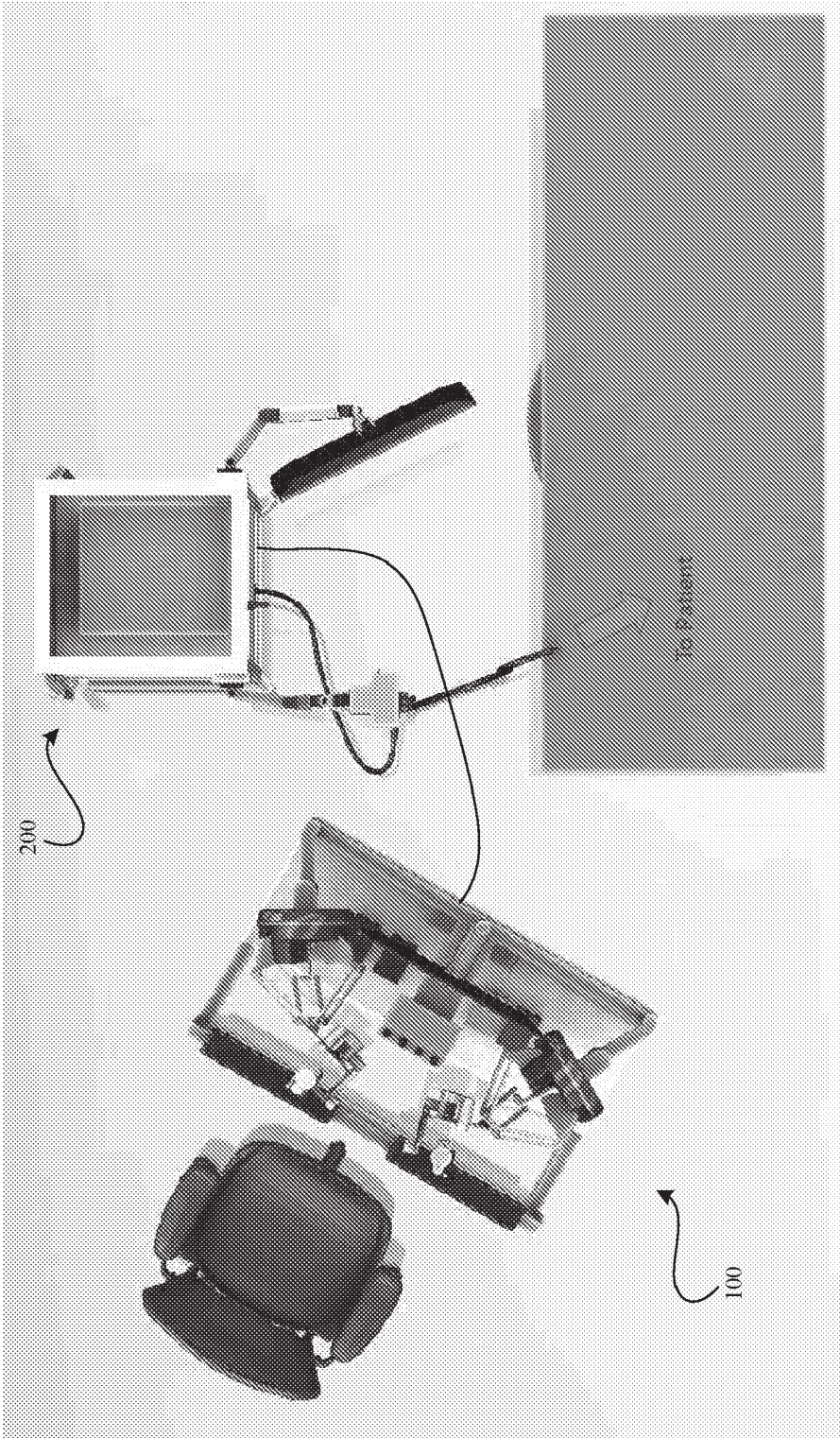
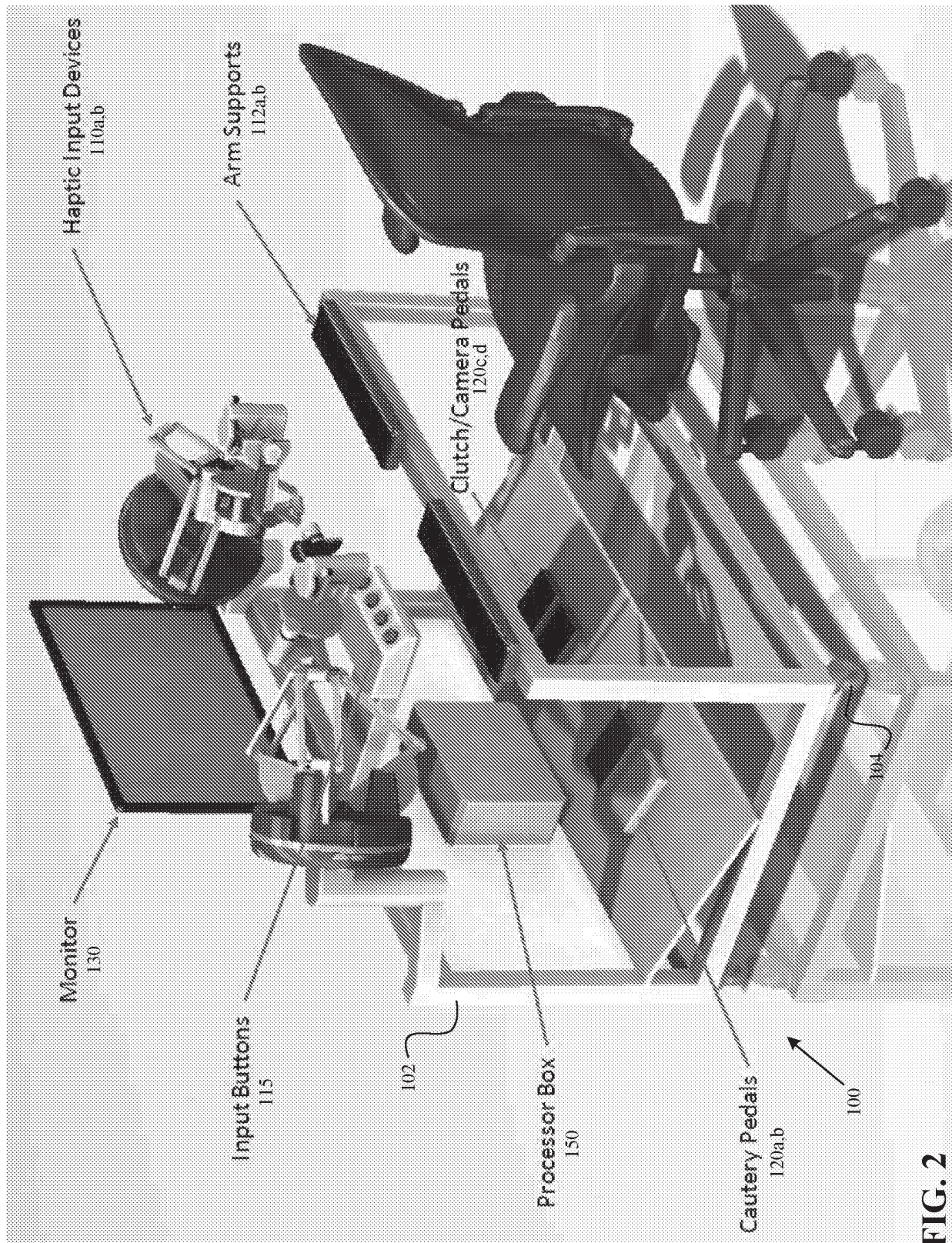
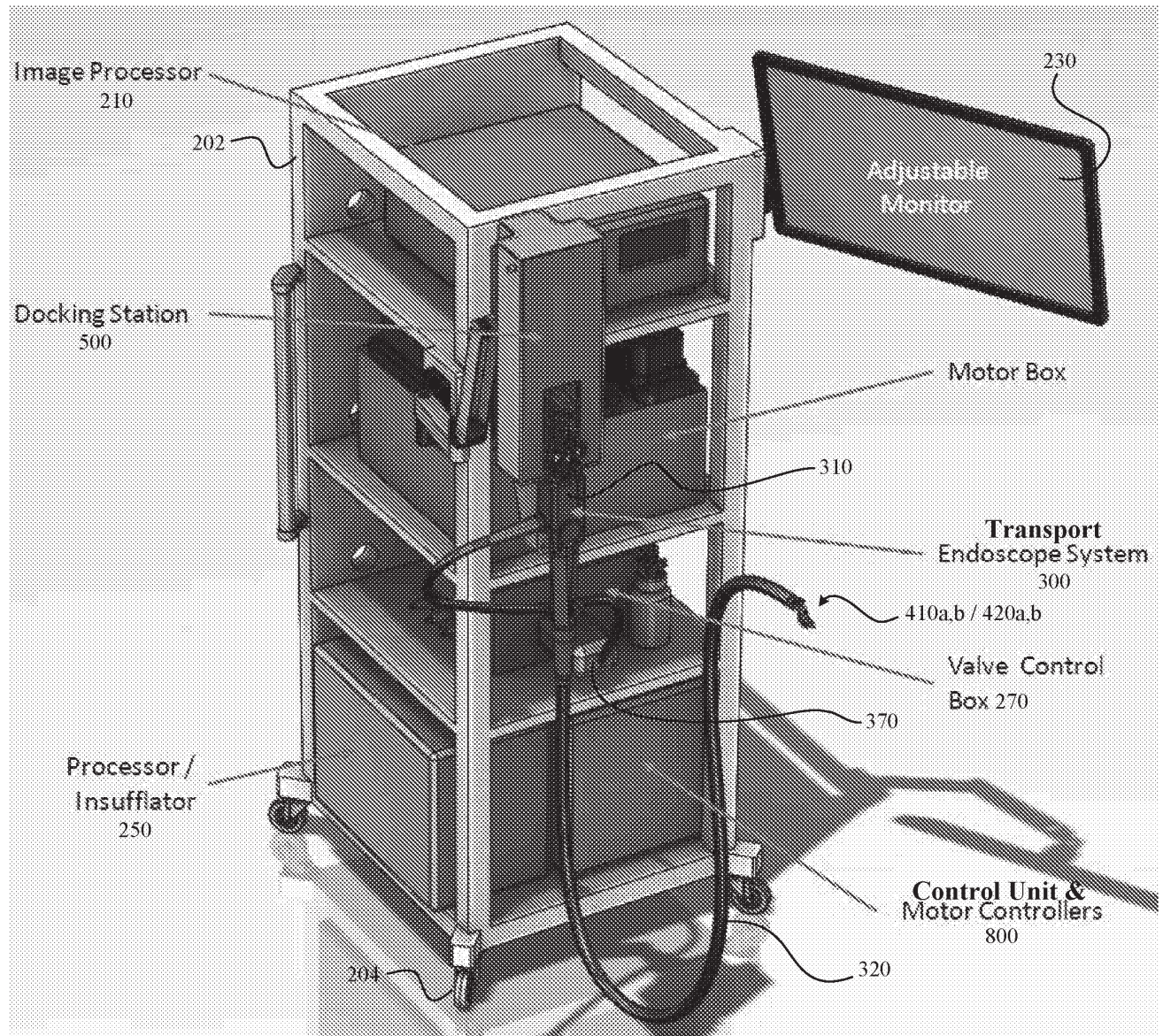


FIG. 1B

3/27



4/27



200

FIG. 3

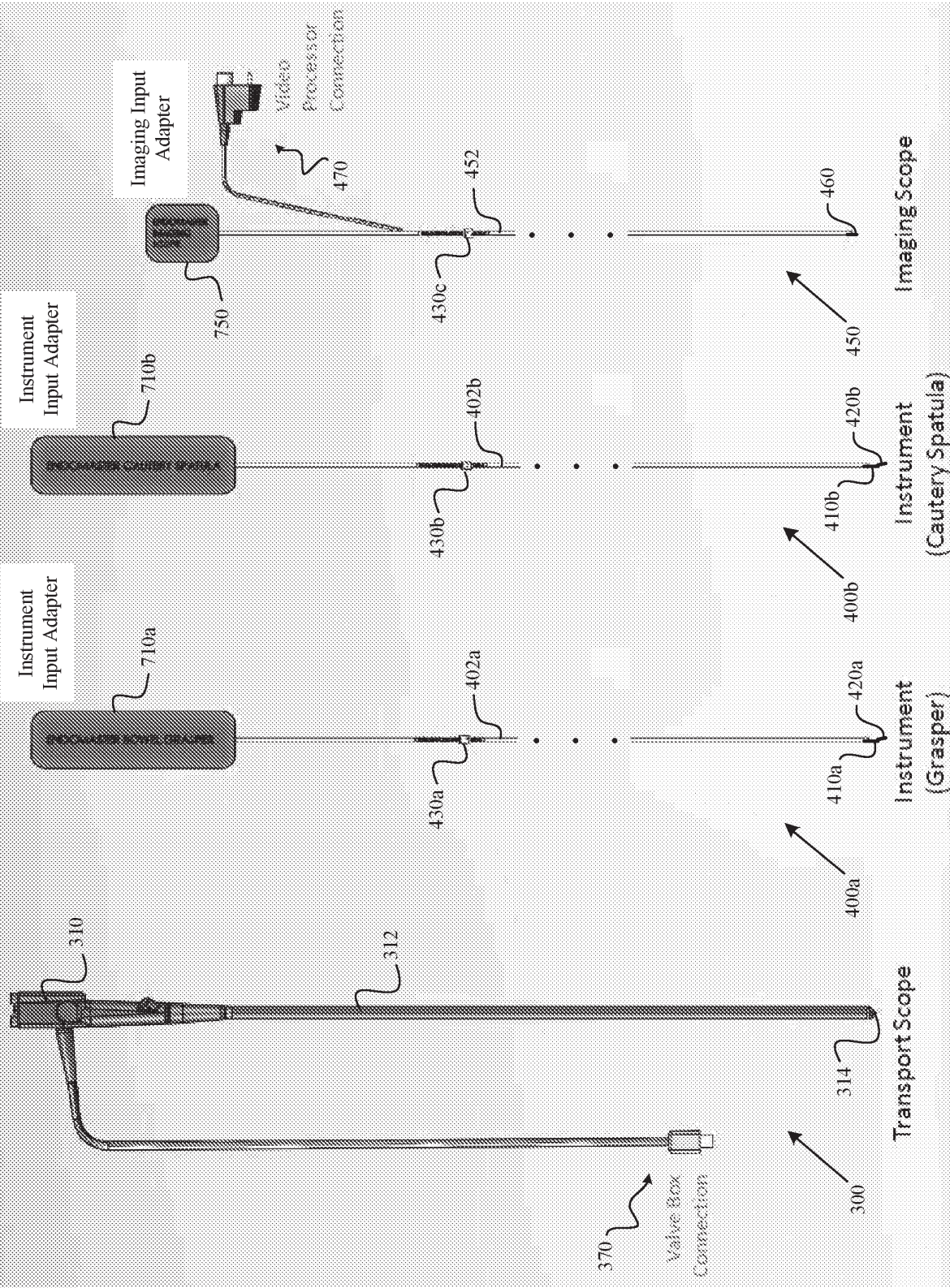


FIG. 4A

FIG. 4B

FIG. 4C

FIG. 4D

6/27

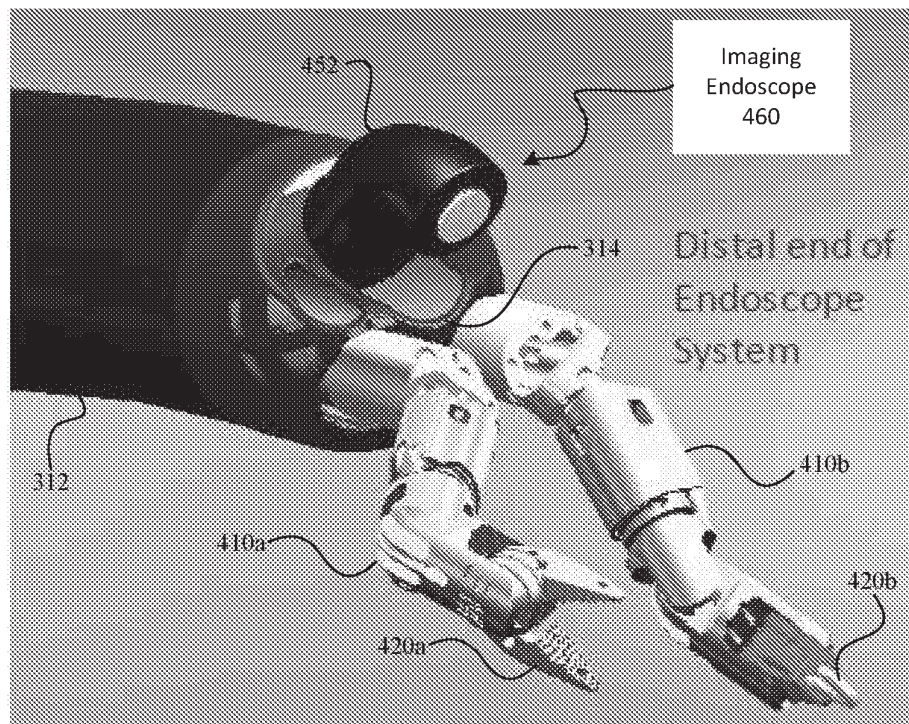


FIG. 5

7/27

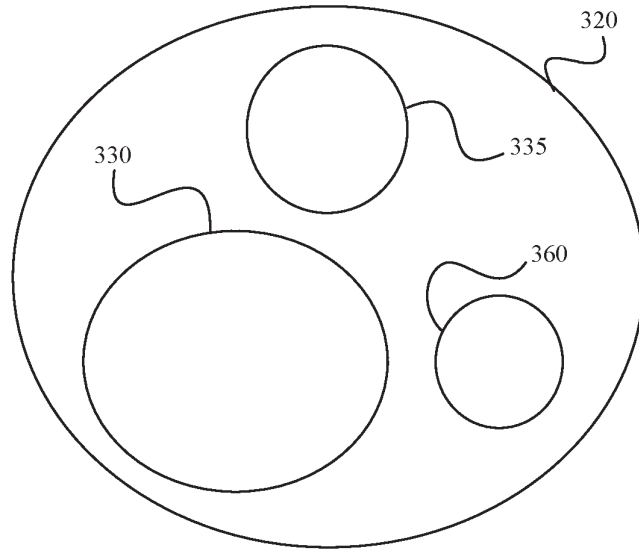


FIG. 6A

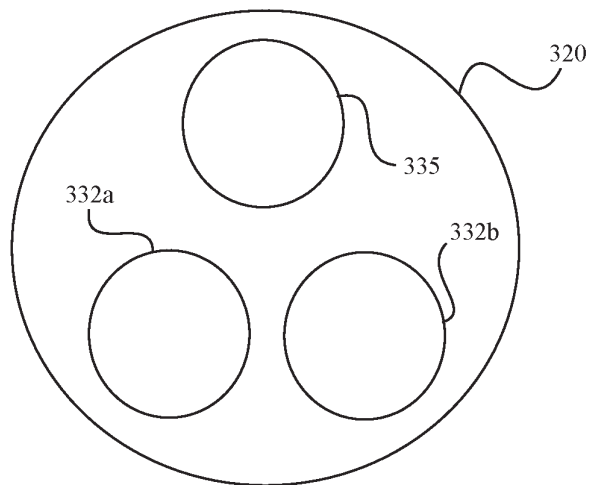
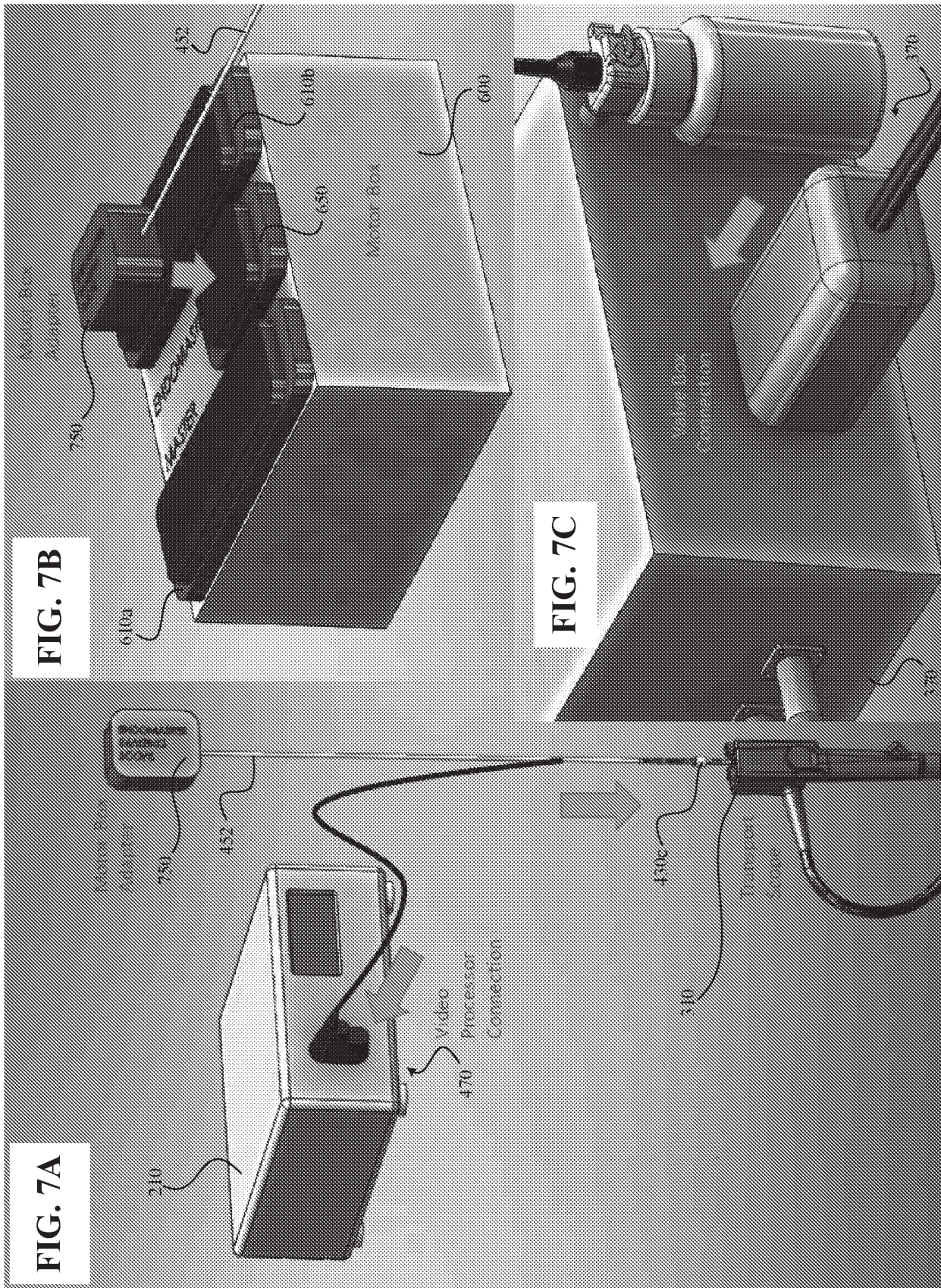
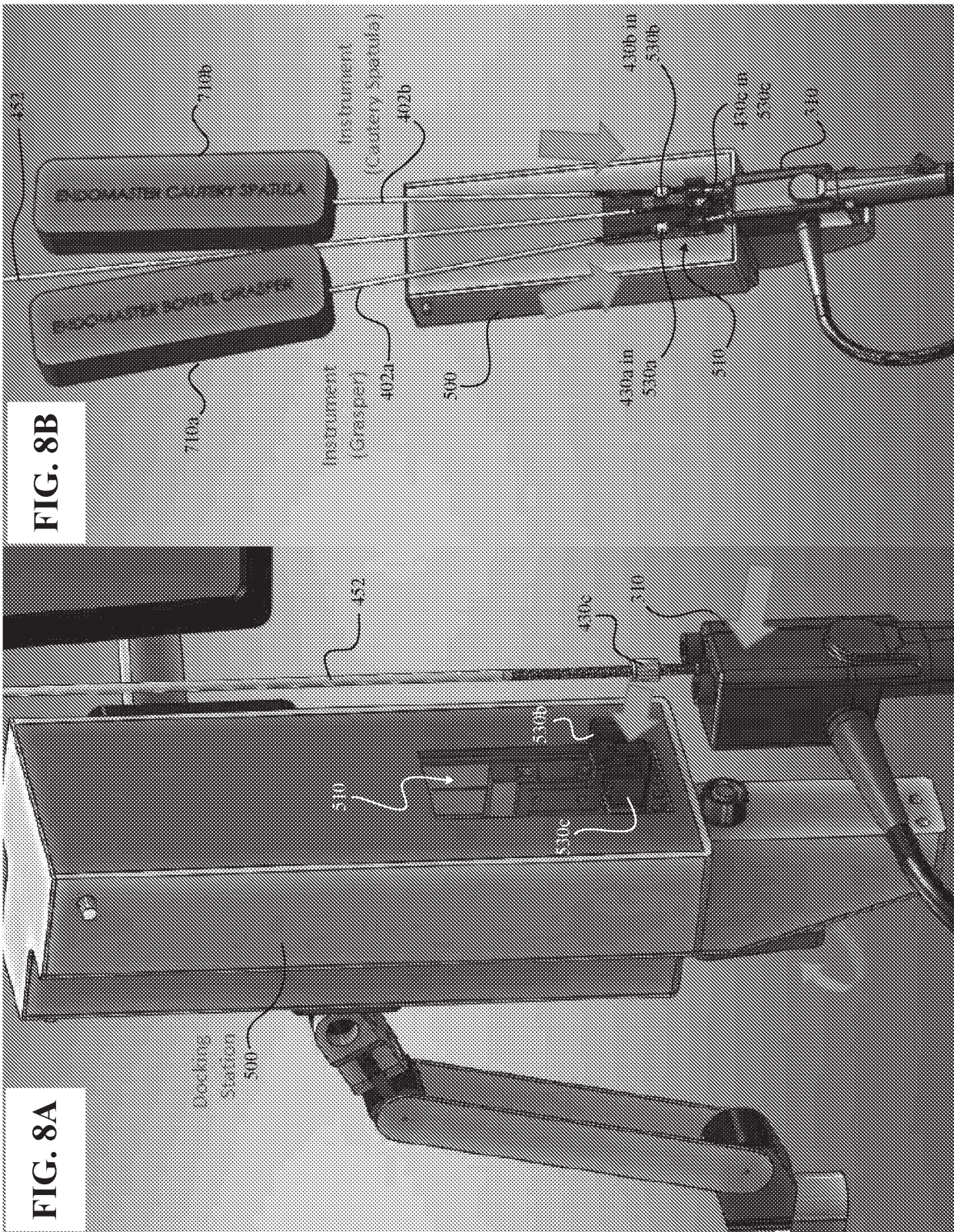


FIG. 6B

8/27



9/27



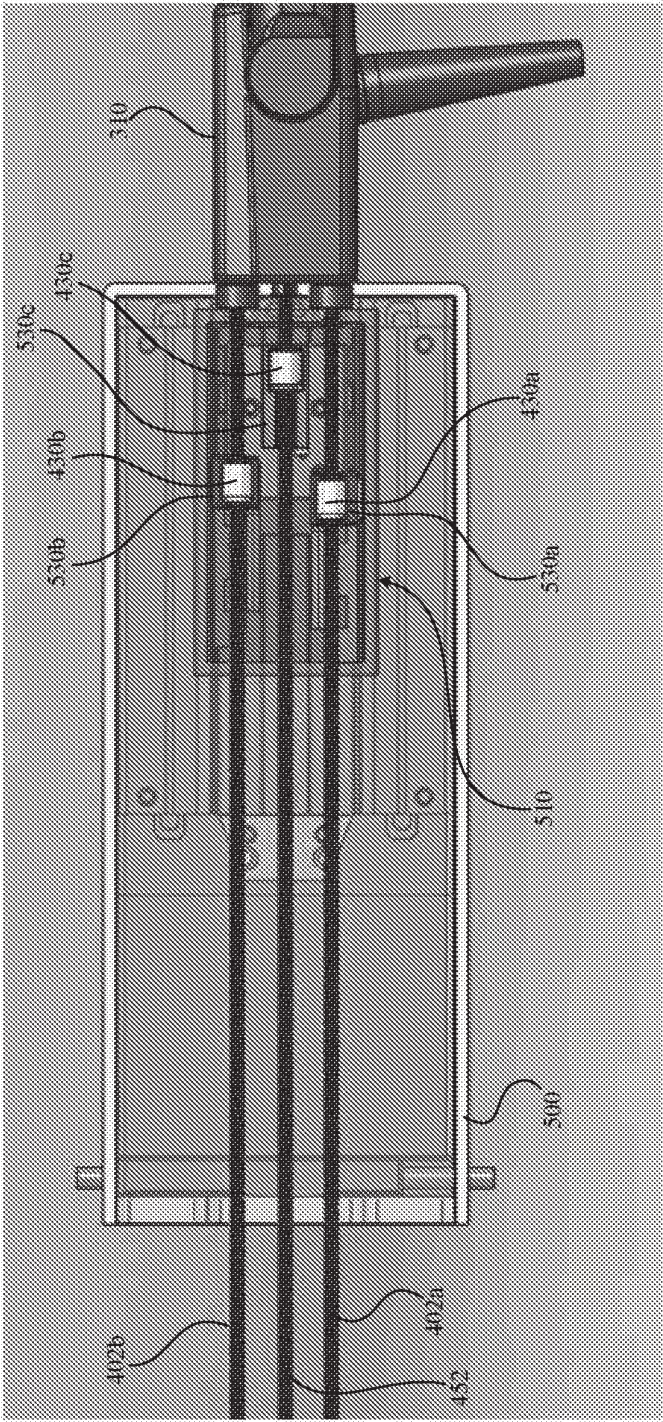
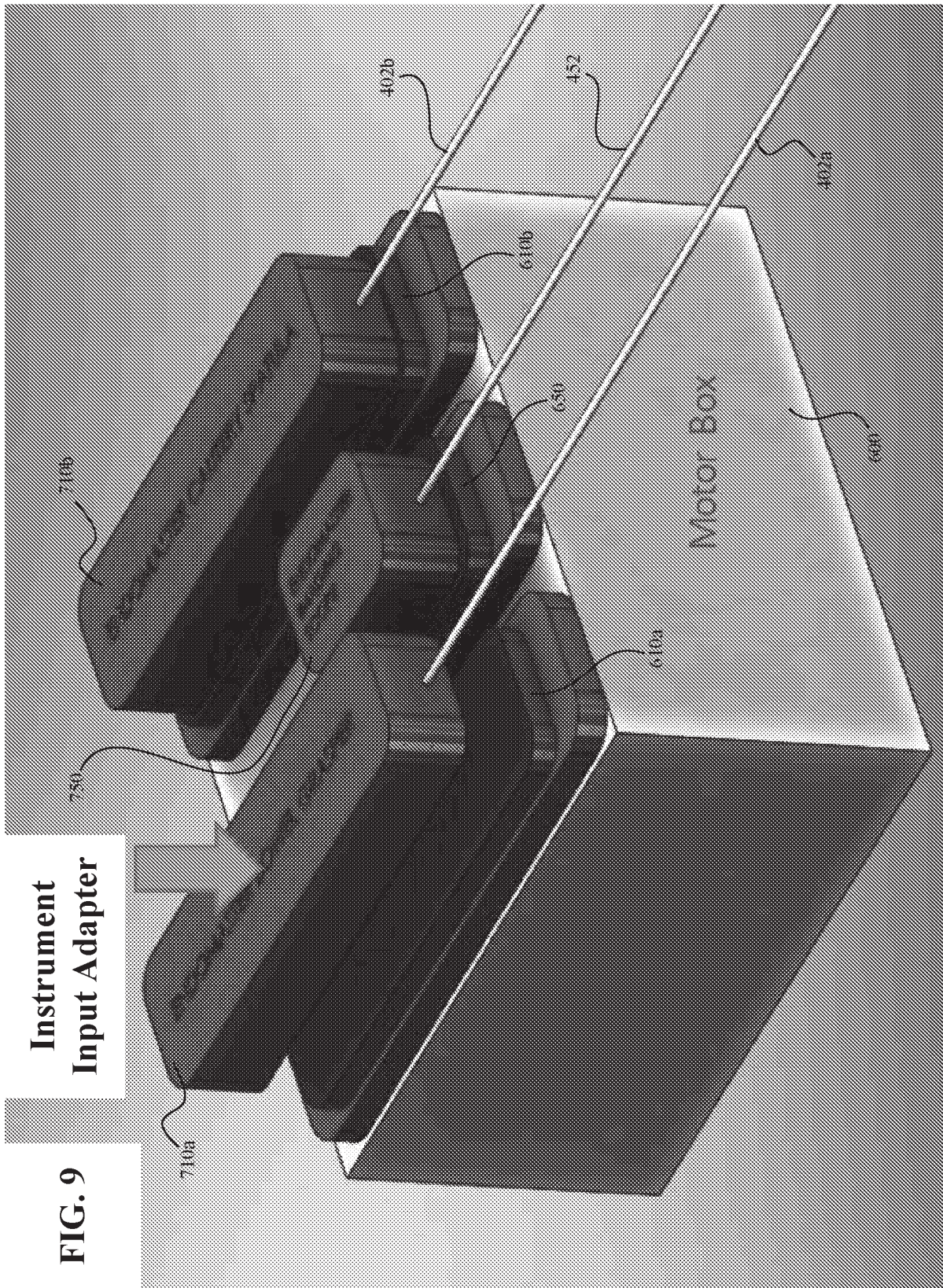


FIG. 8C

11/27



12/27

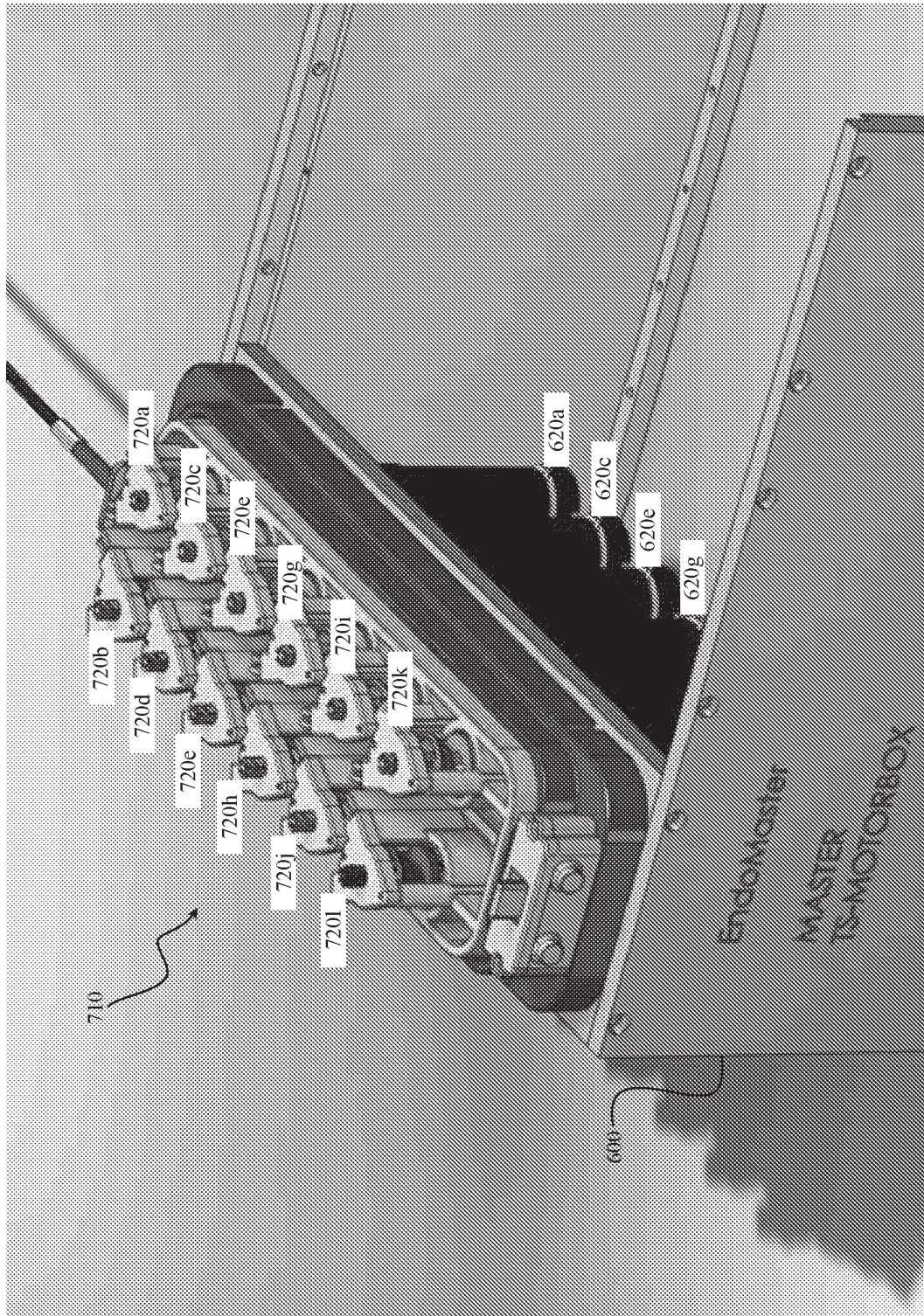


FIG. 10

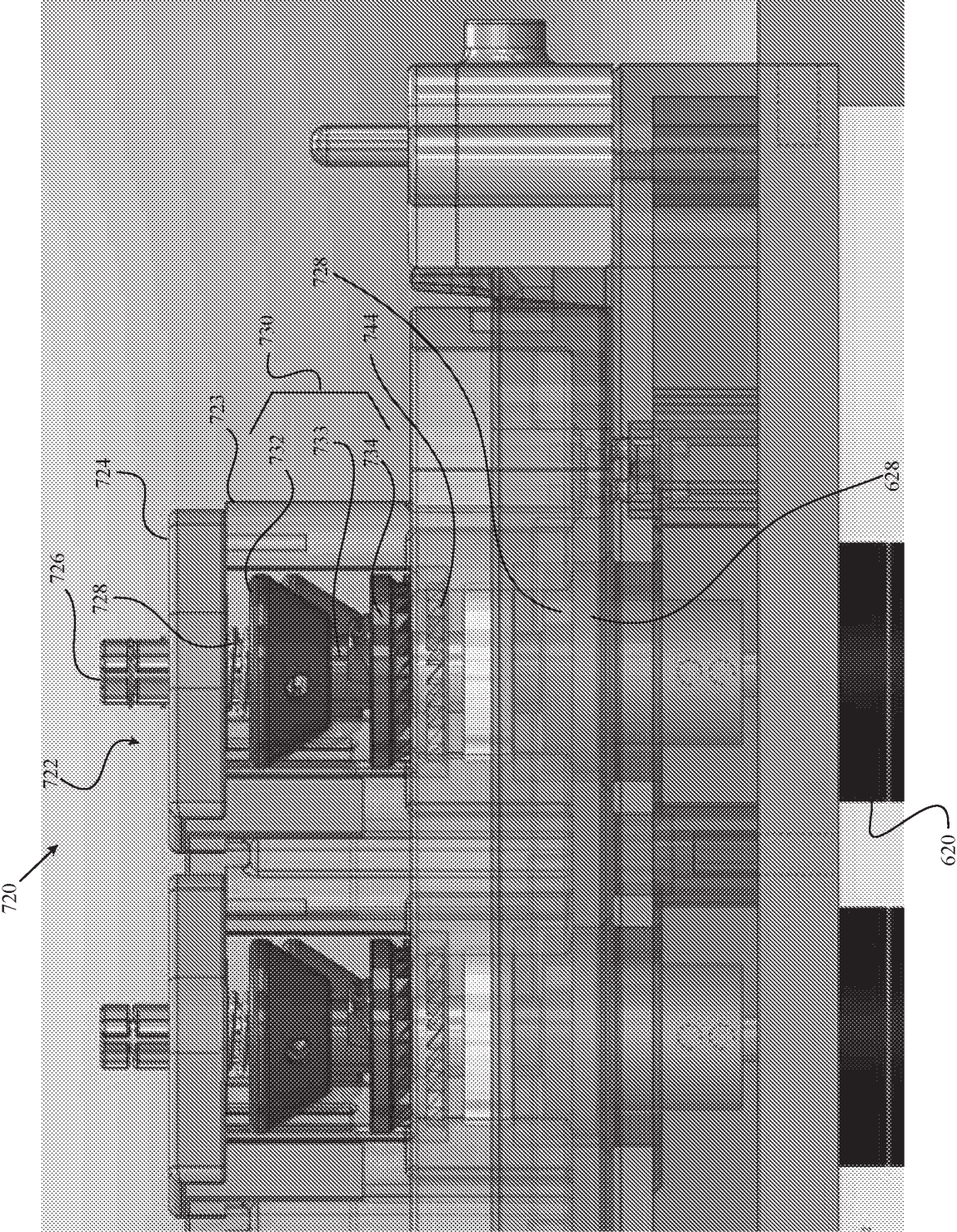


FIG. 11

14/27

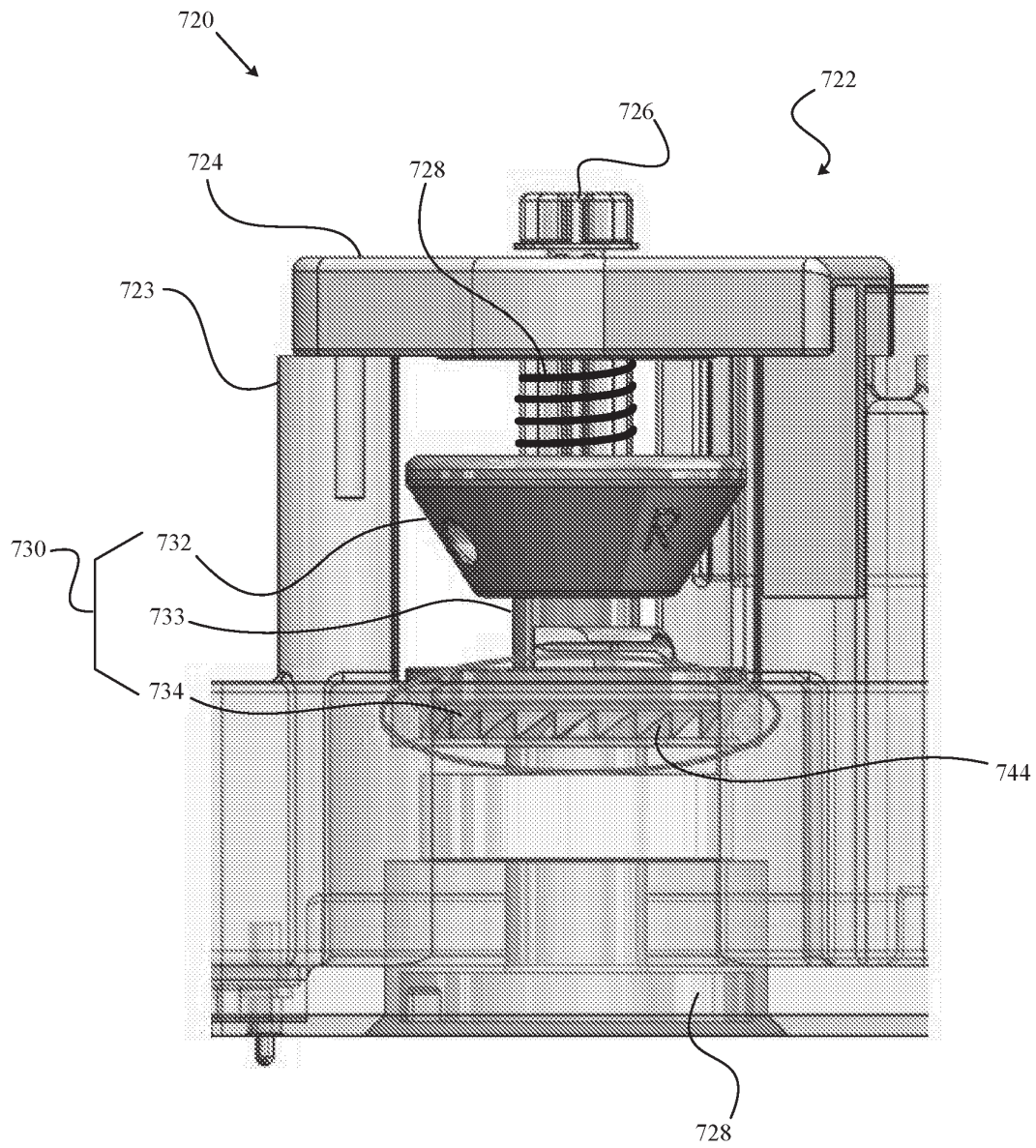


FIG. 12A

15/27

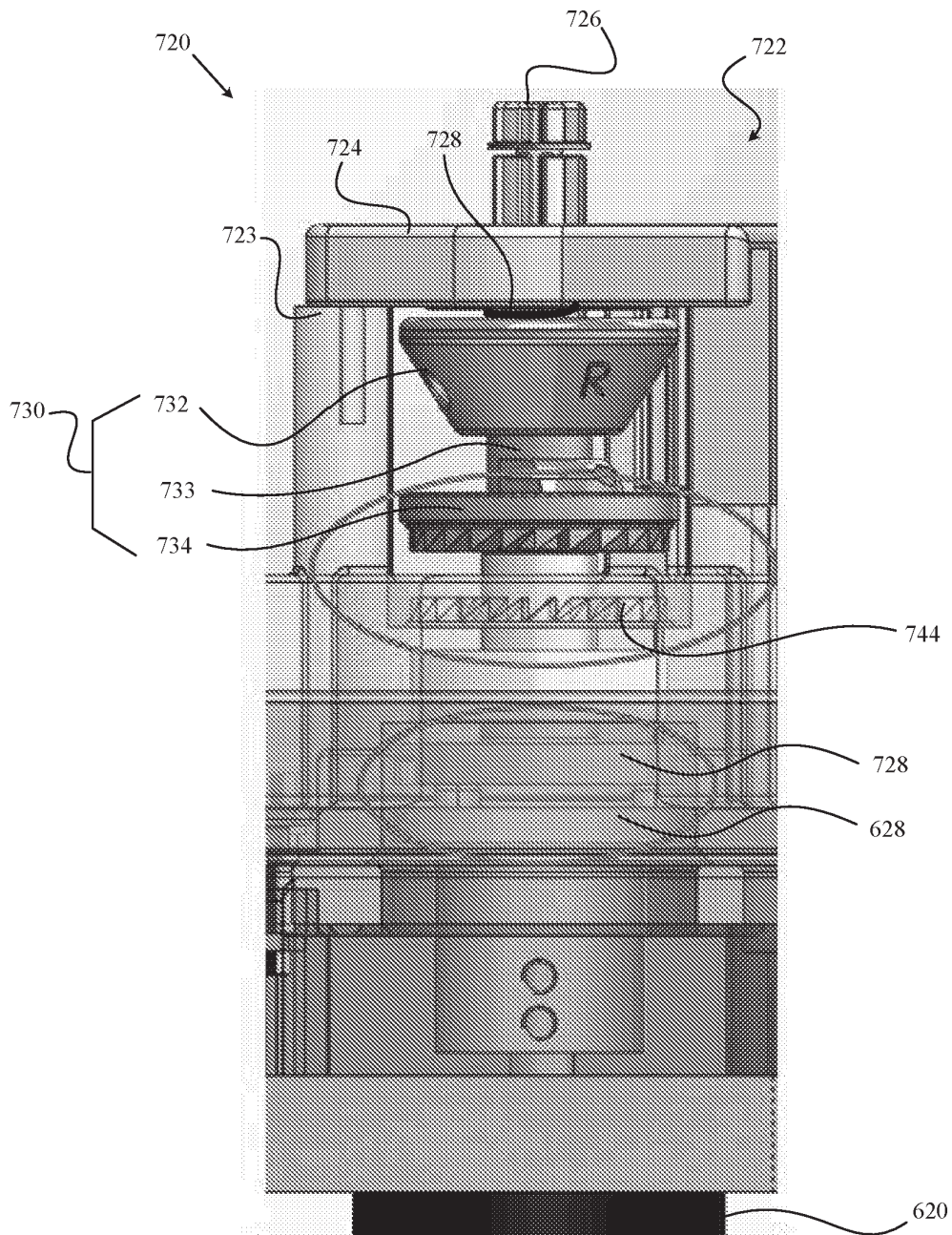


FIG. 12B

16/27

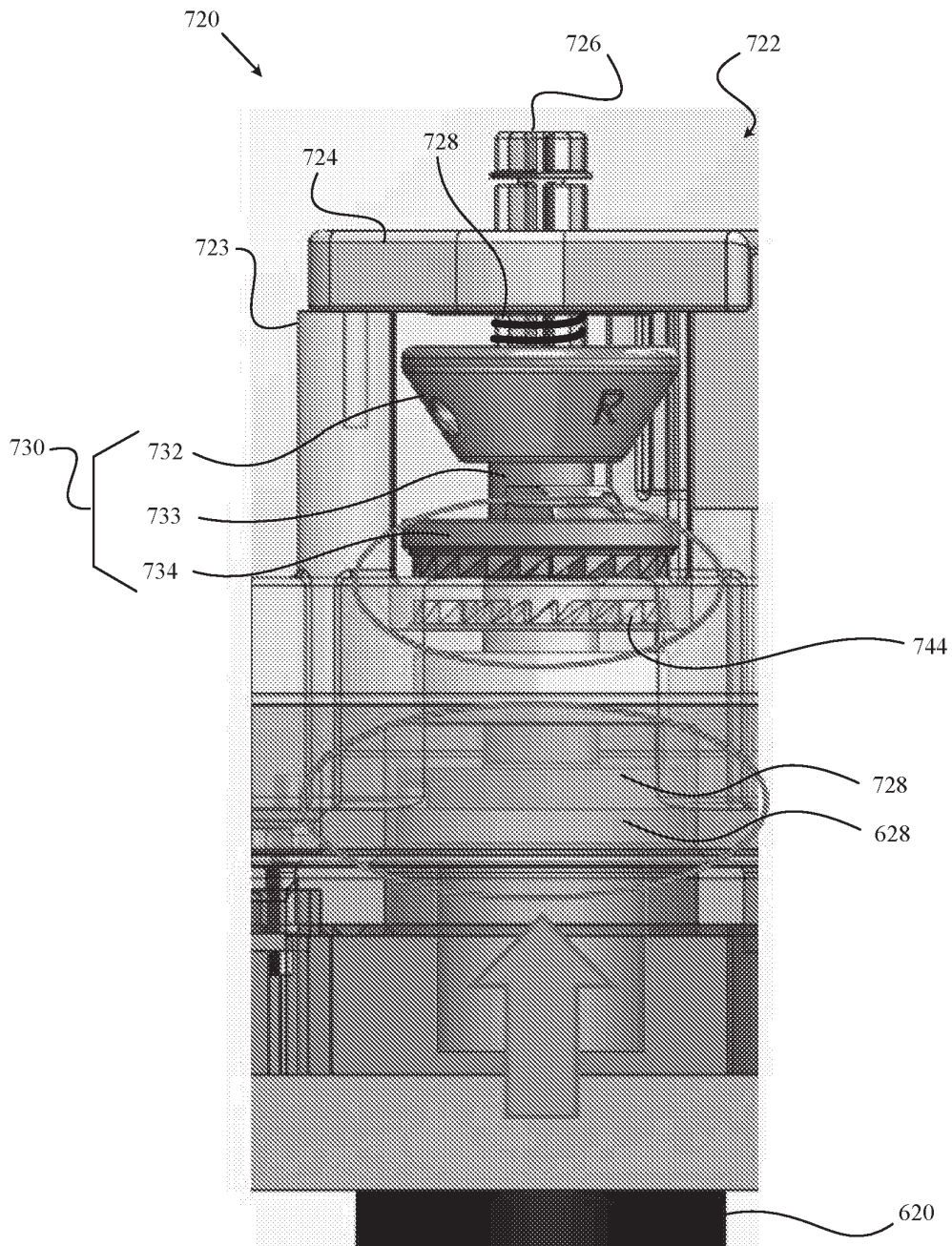


FIG. 12C

17/27

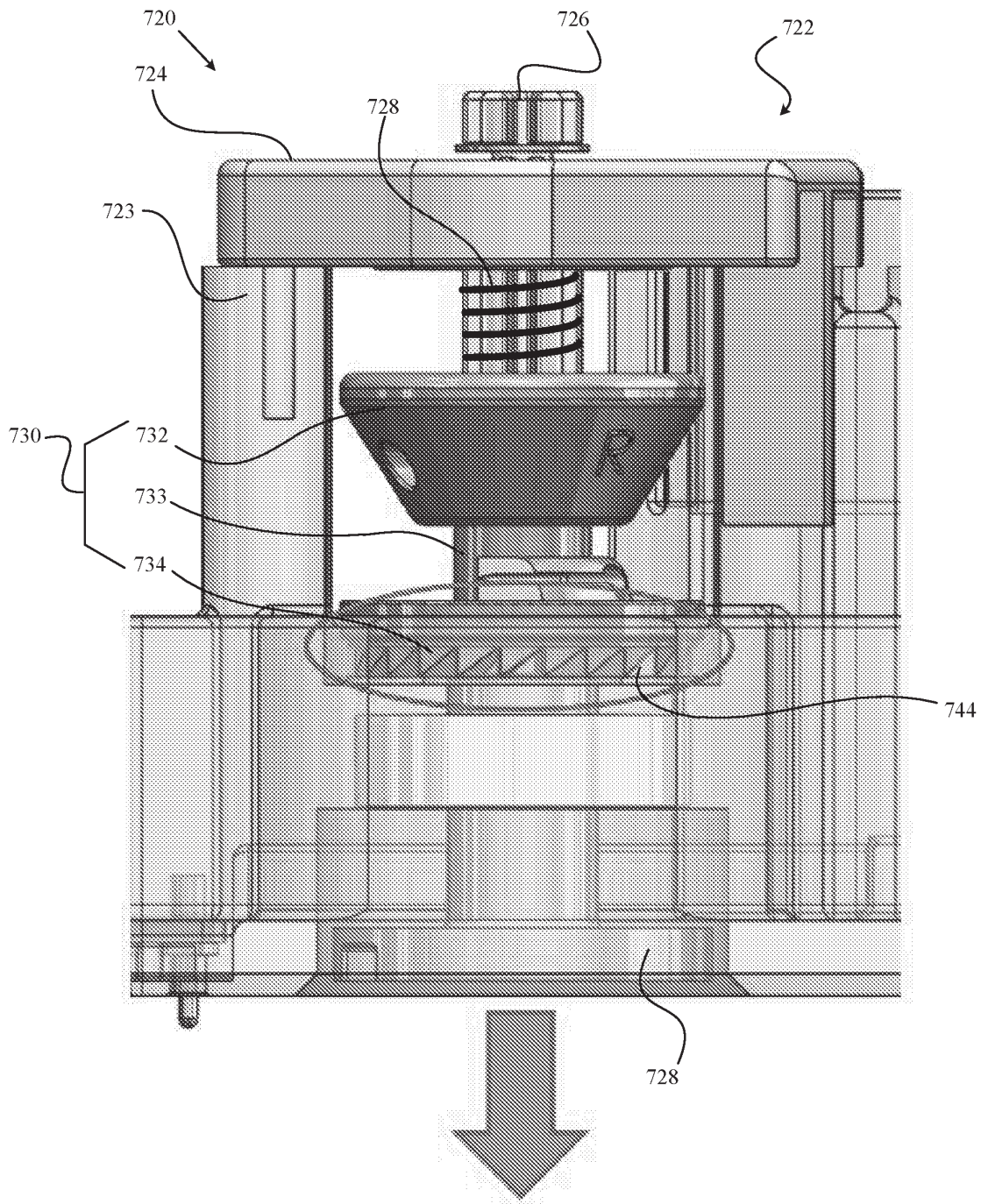


FIG. 12D

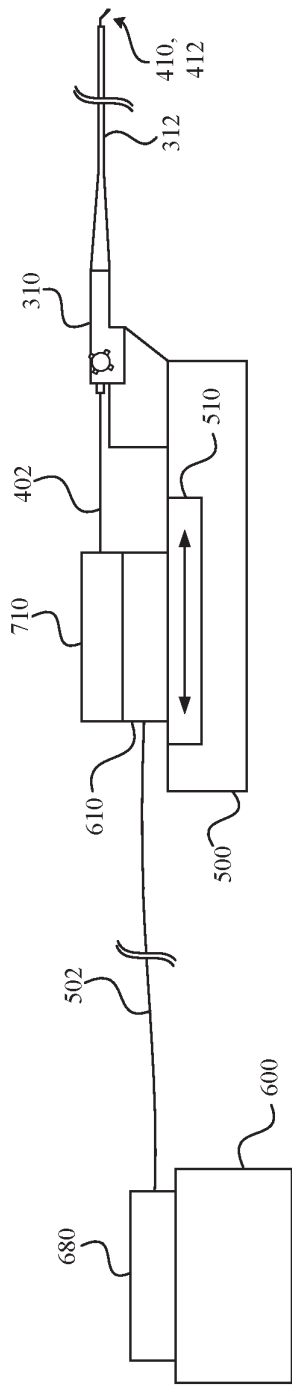


FIG. 13A

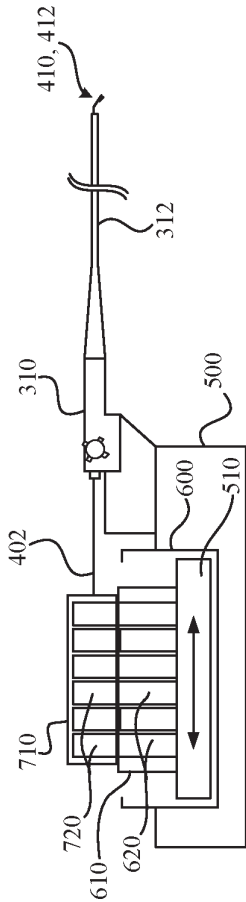


FIG. 13B

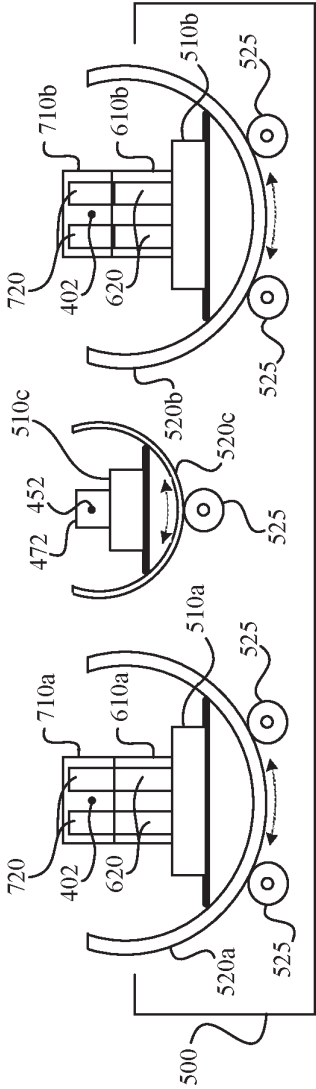


FIG. 13C

20/27

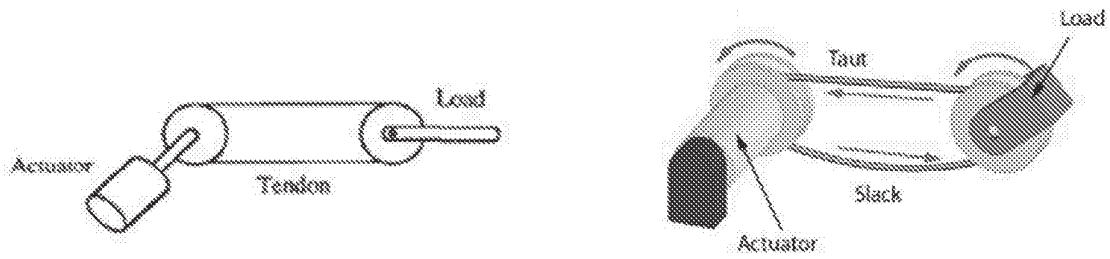


FIG. 14A

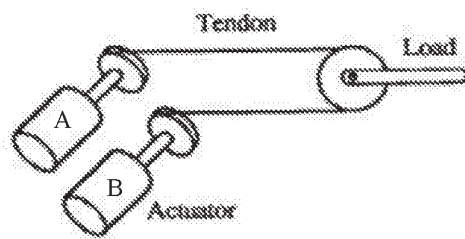
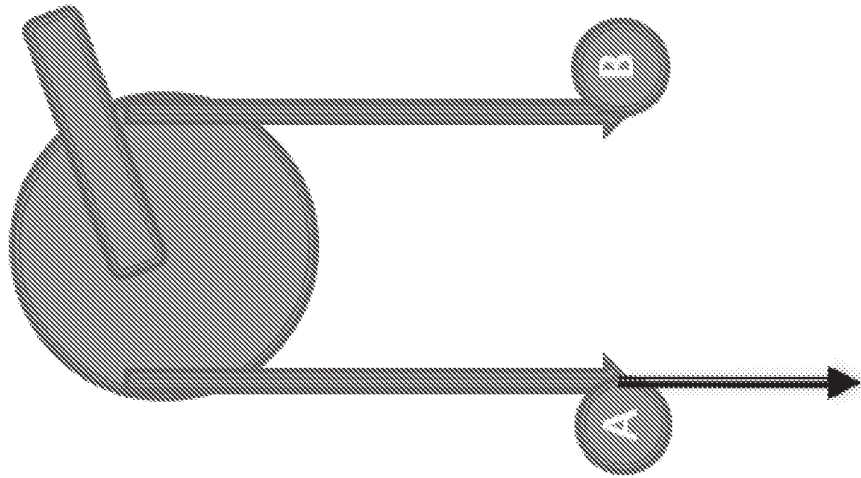


FIG. 14B

FIXED PRETENSIONING – ONLINE / OFFLINE TECHNIQUE



1. Move the end effector distal tip away from the mechanical limits;
2. Turn off Motor B and monitor its position sensor (e.g., an encoder);
3. Apply torque to Motor A and gradually increase it until Motor B's position sensor starts increasing;
4. Record the applied torque (and subtract static friction of Motor B if necessary);
5. Release tension on both tendons;
6. Repeat this procedure a number of times and take only half of the mean torque to determine pretensioning torque parameters for Motor A;
7. Repeat similarly to determine pretensioning torque parameters for Motor B;
8. After releasing tension on both tendons, apply the computed torque to both motors.

This process can be done either offline, i.e., prior to a clinical procedure outside of the OT/OR, or online, i.e., after the instruments are inserted into the transport endoscope and immediately prior to the endoscopic procedure.

FIG. 15

ACTIVE PRETENSIONING (On-the-Fly)

General procedure for active tensioning using the dual motor configuration is as follows:

1. Move the end effector distal tip away from the mechanical limits;
2. Release tension of both tendons and create slack;
3. Apply torque to the motors to pull both tendons at the same speed and keep monitoring the motors' position and torque;
4. Identify the no-slack transition point based upon sensor data, such as by calculating the first and/or second derivative of the motor position and/or torque.

During Step 3, we expect to see a transition. At the beginning, due to the introduced slack in Step 2, a motor winds up the tendon at a constant speed only to remove the slack. There is no change in dynamics, so the motor position increases linearly and the motor torque is constant. When the tendon slack is completely removed and the motor starts stretching the tendon, however, the increment of motor position slows down and the motor torque starts increasing because the motor is basically pulling a stiff spring. This is illustrated in FIG. 16B.

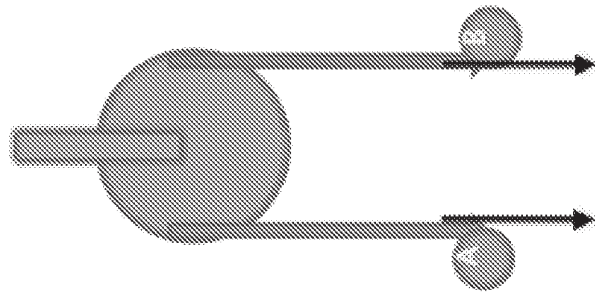


FIG. 16A

23/27

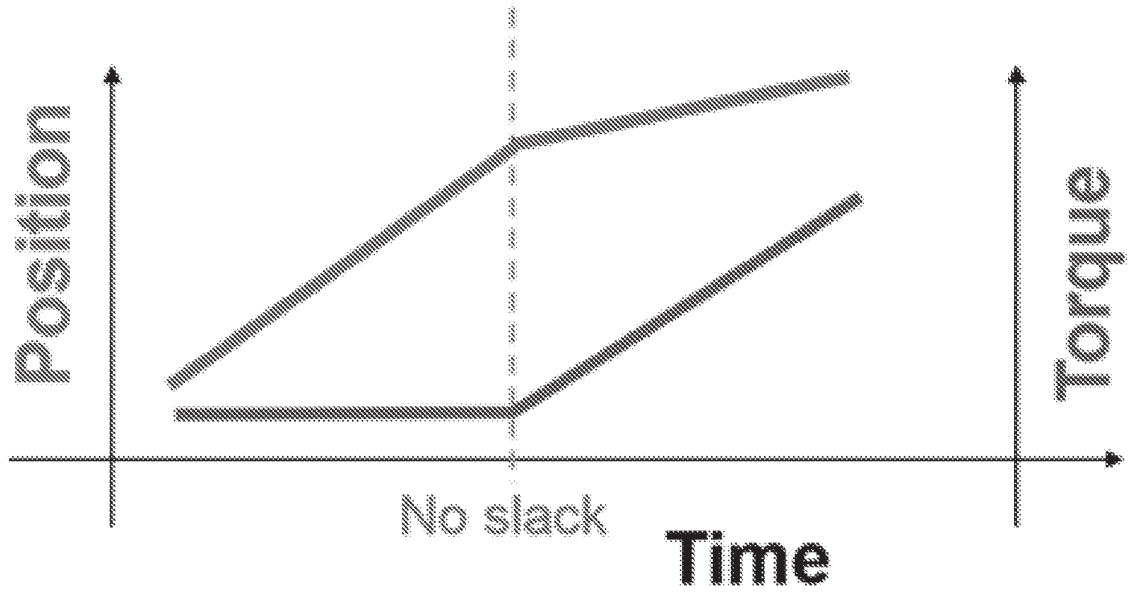


FIG. 16B

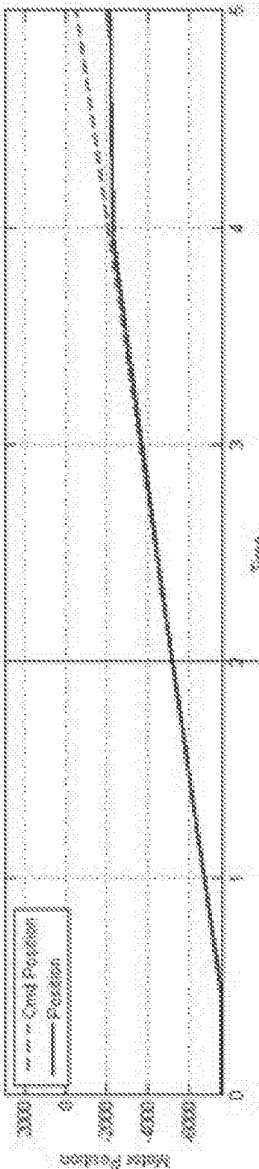


FIG. 16C

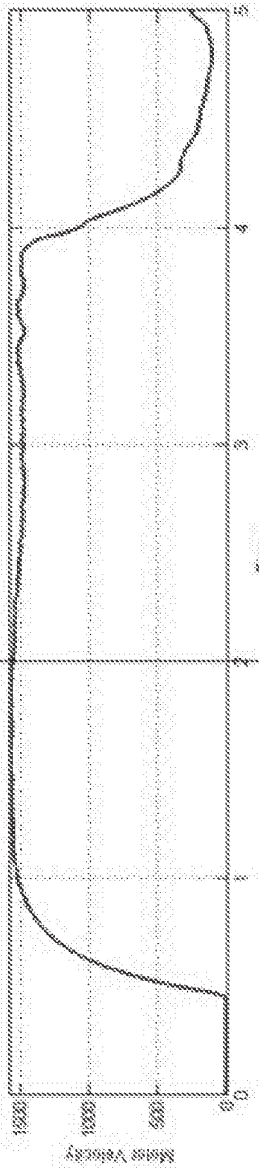


FIG. 16D

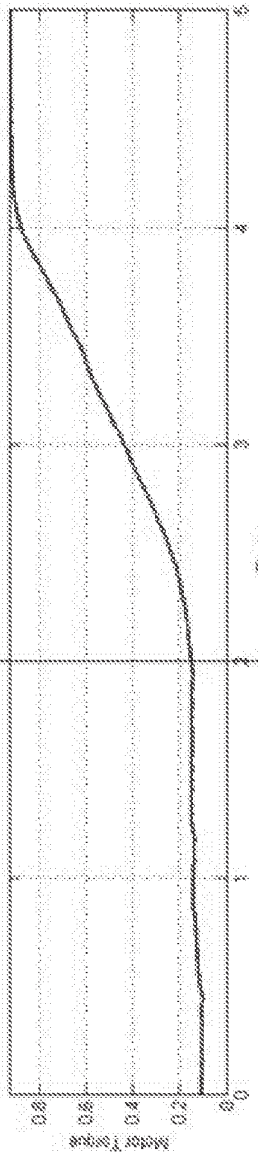


FIG. 16E

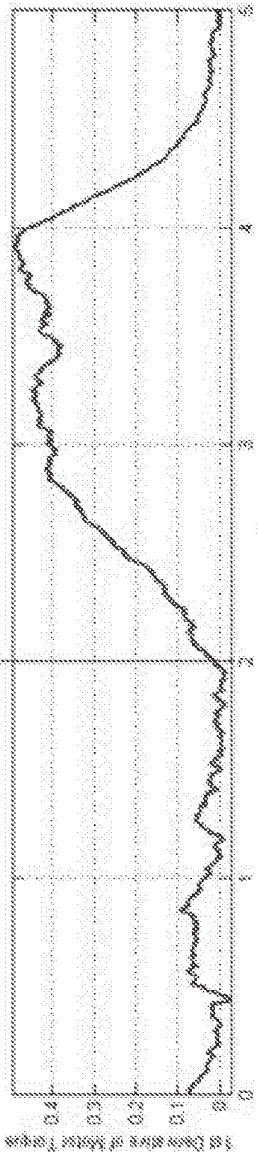


FIG. 16F

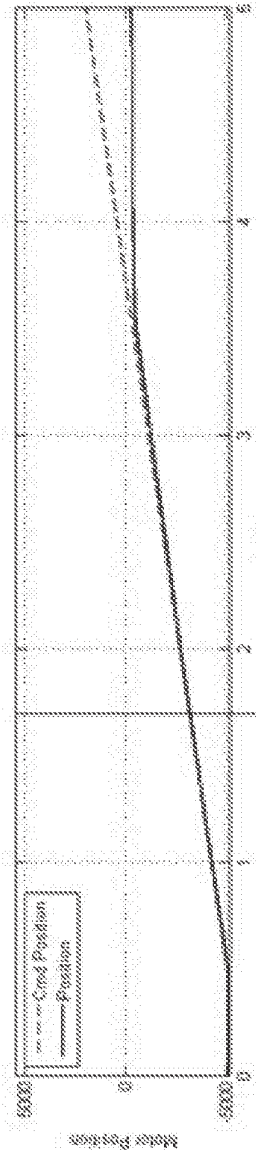


FIG. 16G

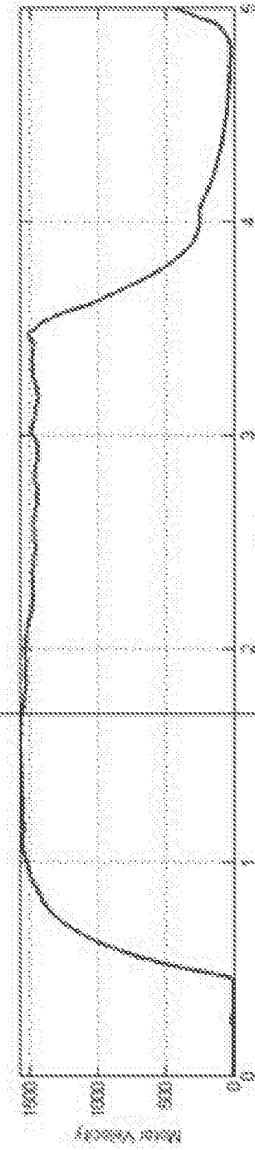


FIG. 16H

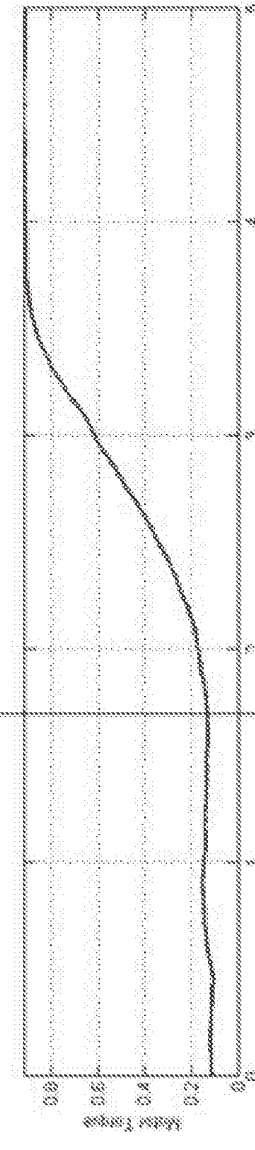


FIG. 16I

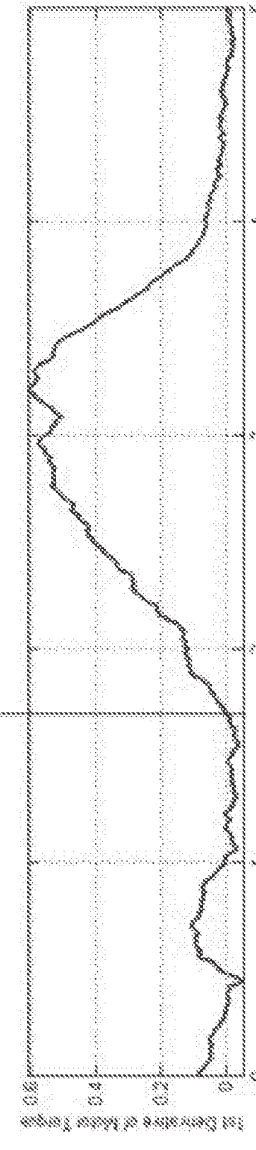


FIG. 16J

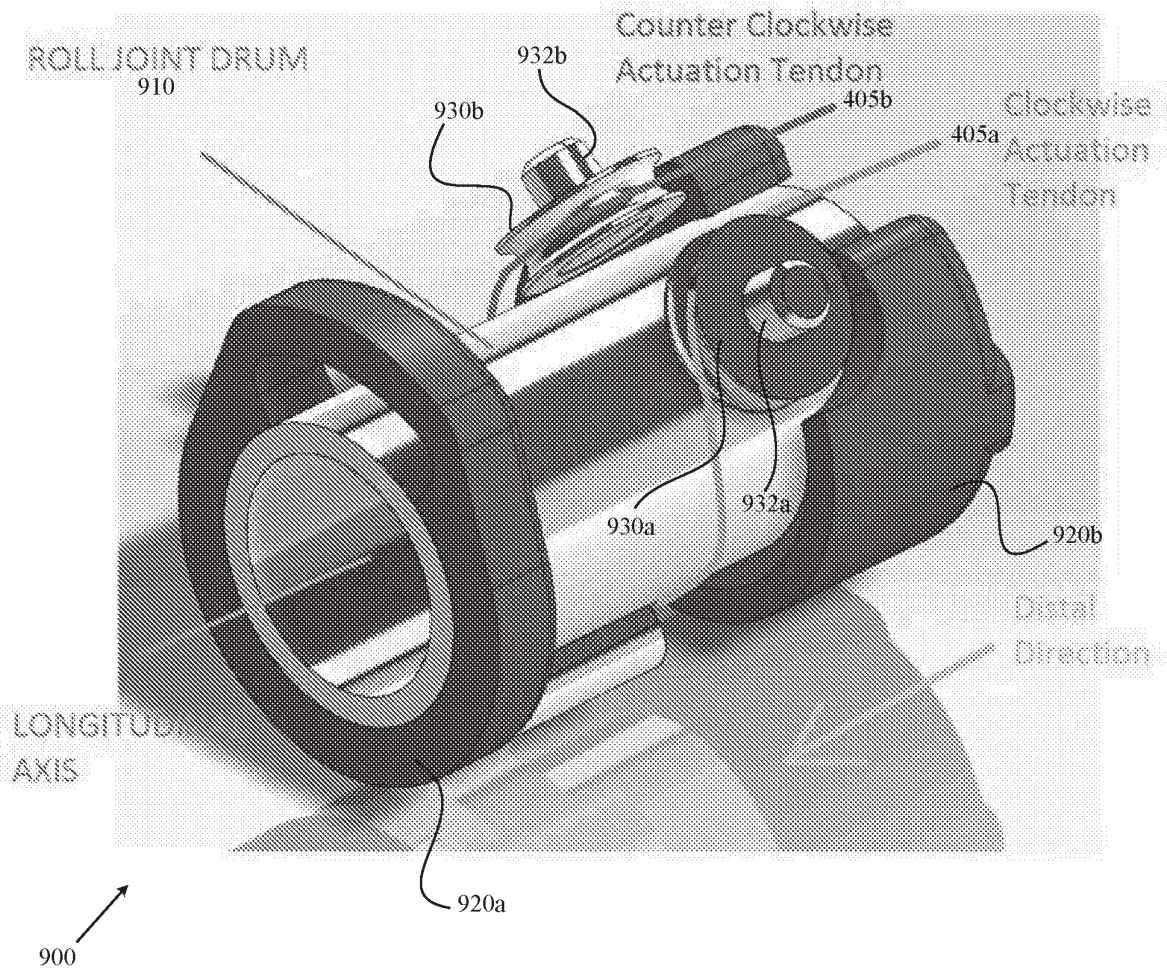


FIG. 17

27/27

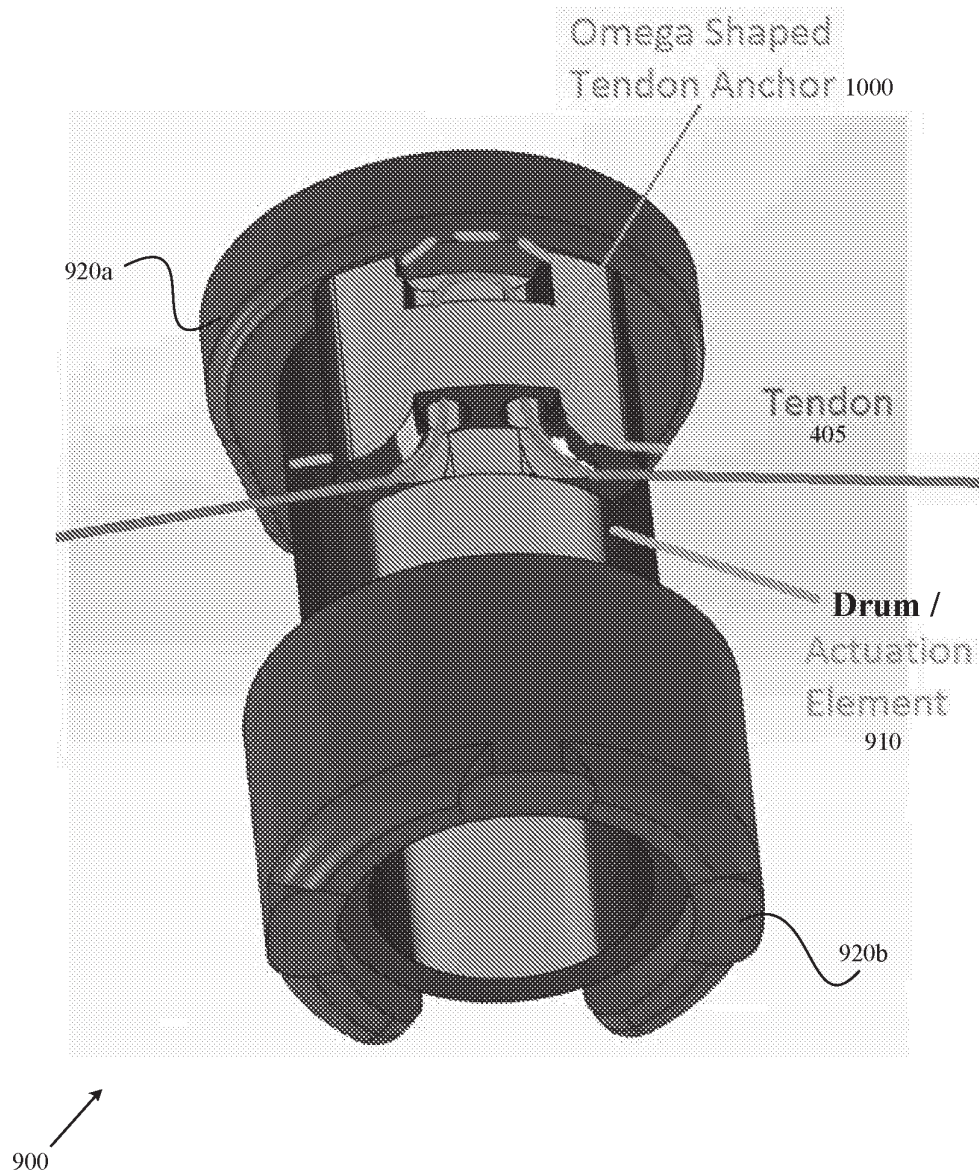


FIG. 18