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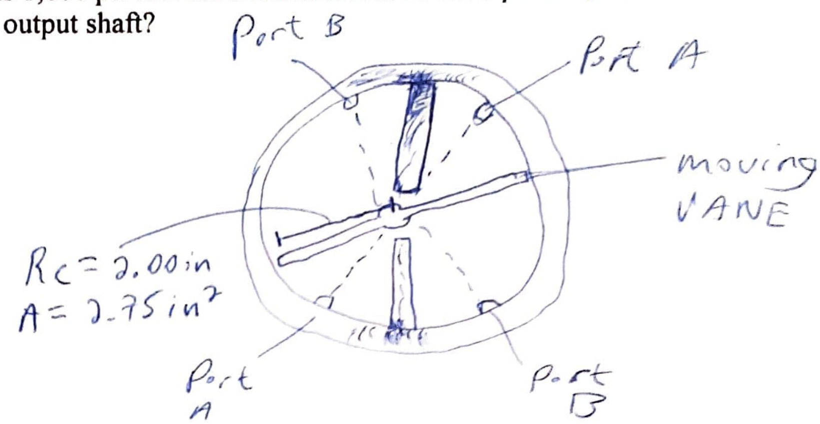
IMSE/CIS 381: Industrial Robots
Assignment # 1

1. A double-action rotary cylinder has a vane radius of 2.00 inches and vane area of 2.75 square inches. If the input fluid pressure is 1,000 psi and the friction loss is 30 inch-pounds, what will be the torque delivered to the output shaft?

• use: $T = (2 \cdot p \cdot A \cdot R_c) - T_f$



PSI of input pressure = 1,000 psi

T_f = 30 in-pounds

$$T = 2\left(1{,}000\,\frac{lb}{\cancel{in^2}} \cdot 2.75\,\cancel{in^2} \cdot 2.00\,in\right) - 30\,in\text{-}pounds$$

$$T = 2(2750\,lb \cdot 2\,in) - 30\,in\text{-}lb$$

$$T = 2(5500\,lb\text{-}in) - 30\,in\text{-}lb$$

$$T = (11000\,in\text{-}lb) - (30\,in\text{-}lb)$$

$$\boxed{T = 10970\,in\text{-}lb}$$ Solution

$V = IR$; $I = \frac{V}{R}$

2. A DC servomotor is used to actuate a robot joint. It has a torque constant of 10 in-lb/A, and a voltage constant of 12 V/Kr/min (1 Kr/min = 1000 rev/min). The armature resistance is 2.5 Ω. At a particular moment during the robot cycle, the joint is not moving and a voltage of 25 V is applied to the motor.

   a. Determine the torque of the motor immediately after the voltage is applied.

   b. As the motor accelerates, the effect of the back-emf is to reduce the torque. Determine the back-emf and the corresponding torque of the motor at 250 and 500 rev/min.

(a)

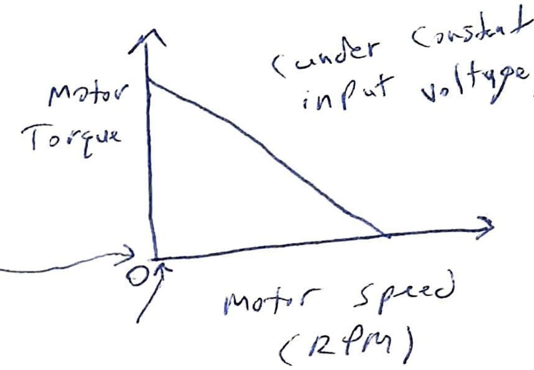
$K_m = (10 \text{ in-lb})/A$ (Torque Const)

$K_b = 12 \text{ V/Kr/min}$ (voltage Const)

Armature Res $= 2.5\,\Omega = R$

* joint is stationary ; $e_b = 0$ (back EMF)

* $V_{in} = 25\text{ V}$



• use $I_a(t) = \frac{V_{in}(t) - e_b(t)}{R} = \frac{25\text{v} - 0\text{v}}{2.5\,\Omega} = 10\text{A}$

and

$T_m = K_m \cdot I_a = \frac{10 \text{ in-lb}}{A} \cdot \frac{10A}{1} = \boxed{100 \text{ in-lb}}$

Solution to (a)

(b) use $e_b = K_b \cdot \omega$

$I_a(250 \frac{rev}{min}) = \frac{25\text{v} - 3\text{v}}{2.5\,\Omega} = \frac{22}{2.5} = 8.8\text{A}$

$I_a(500 \frac{rev}{min}) = \frac{(25-6)\text{v}}{2.5\,\Omega} = 7.6\text{A}$

$e_b(250 \frac{rev}{min}) = \left(\frac{12\text{v}}{\left(\frac{Kr}{min}\right)}\right) \cdot \frac{\left(250 \frac{rev}{min}\right)}{1} = \frac{3000\text{V} \cdot \frac{rev}{min}}{\left(1000 \frac{rev}{min}\right)} = 3\text{V}$

$e_b(500 \frac{rev}{min}) = \frac{12\text{v}}{1000 \frac{rev}{min}} \cdot 500 \frac{rev}{min} = \frac{12\text{V} \cdot 500}{1000} = 6\text{V}$

$(250 \frac{rev}{min}) \rightarrow T_m = \left(\frac{10 \text{in-lb}}{A}\right) \cdot 8.8A = \boxed{88 \text{ in-lb}}$

$(500 \frac{rev}{min}) \rightarrow T_m = \frac{10 \text{ in-lb}}{A} \cdot 7.6A = \boxed{76 \text{ in-lb}}$

3. A stepping motor is to be used to actuate one joint of a robot arm in a light duty pick-and-place application. The step angle of the motor is 10°. For each pulse received from the pulse train source, the motor rotates through a distance of one step angle.

   a. How many pulses are required to rotate the motor through a total of three complete revolutions?

   b. If it is desired to rotate the motor at a speed of 25 rev/min, what pulse rate must be generated by the robot controller?

(a)

Step angle = 10°

Res. = 36

* Resolution of step motor

~~Res = (Step L)(360°)~~

$\rightarrow$ Res. = $\frac{360°}{\text{step } L} = \frac{360°}{10°} = 36$

a) Solution: (36 pulses) for ~~for~~ 1 complete; so (36) × (3) for 3 complete Revolutions = 36 · 3 = $\boxed{108 \text{ pulses}}$

From Slides: "resolution is det. by the # of poles in the stator and rotor"

(b)

Desired Rotation: $\omega = 25 \frac{Rev}{min}$

* Find Pulse rate = $\frac{\text{pulses}}{\text{min}}$

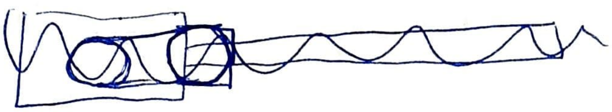
* 36 pulses = 1 revolution

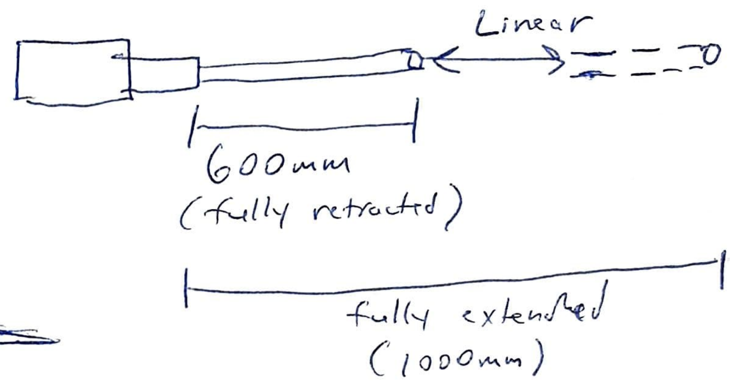
* ~~36 pulses~~

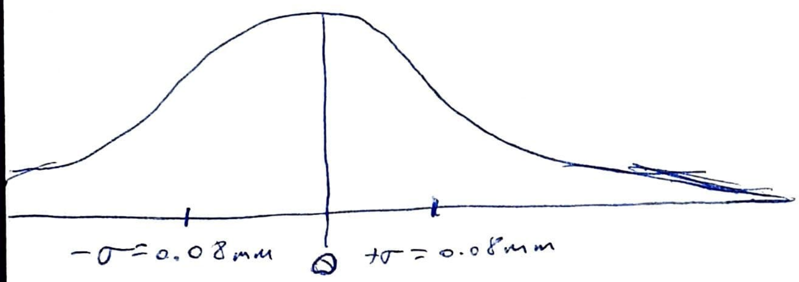
* So (25)(36 pulses) = 900 pulses

Solution: You need $\frac{900 \text{ pulses}}{\text{minute}}$ = $\boxed{\frac{25 \text{ rev}}{m}}$

4. The linear joint type (L) of a certain industrial robot is actuated by a piston mechanism. The length of the joint when fully retracted is 600 mm and when fully extended is 1000 mm. the mechanical errors associated with the linear joint form a normal distribution in the direction of the joint actuation with standard deviation = 0.08 mm. If the robot's controller has an 8-bit storage capacity. Determine: (a) control resolution (b) spatial resolution, (c) accuracy, and (d) repeatability for the robot.







- 8-bit storage capacity; $2^n = \#$ of Addressable points $= 2^8 = 256$
- Control Res $\rightarrow$ $CR = \dfrac{\text{Range}}{\#\text{ of Add pts.}} = \dfrac{\text{Range}}{2^n} = \dfrac{400\text{ mm}}{256} = 1.5625$ mm
- Range of joint $= \underset{\text{(Full ext.)}}{1000\text{mm}} - \underset{\text{(Full retr.)}}{600\text{mm}} = 400$mm

a $\boxed{CR = 1.5625\text{ mm}}$

- Spatial Res. $(SR) = CR + 6\sigma = 1.5625\text{mm} + (6)(0.08\text{mm}) \rightarrow$

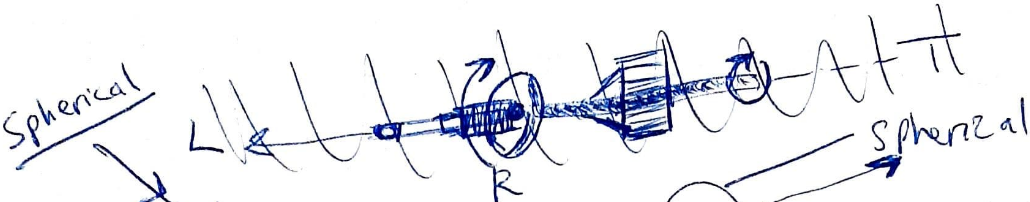
$\rightarrow \boxed{SR = 2.0425\text{mm}}$ b

- Accuracy $= (0.5)(SR) = \frac{1}{2}SR = \frac{SR}{2} = \dfrac{2.0425\text{mm}}{2} = 1.02125$mm

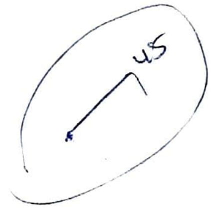
$\boxed{\text{Accuracy} = 1.02125\text{mm}}$ c

- Repeatability $= \pm 3\sigma$; $R = \pm 3(0.08\text{mm})$

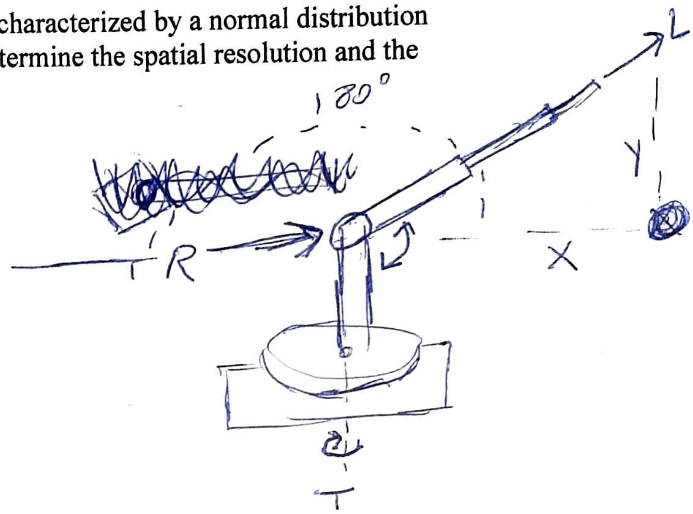
$\rightarrow \boxed{R = \pm 0.24\text{mm}}$ d



5. A cylindrical configuration robot has three joints TRL. The control system for the robot has a 12 bits storage capacity for each joint. The telescoping joint (L) obtains its vertical motion by the rotational joint (R) about a horizontal axis. The total range of rotation is 180degrees. When fully extended, the robot's telescoping link measures 75 inches from the pivot point. When fully retracted robot's telescoping link measures 30 inches from the pivot point. Determine the following:



a. The control resolution for both the L and R axes,
b. The combined control resolution of the R and L axes in linear scale when the telescoping arm is fully extended and fully retracted.
c. If the mechanical inaccuracy of the L axis can be characterized by a normal distribution with standard deviation equals 0.0008 inches. Determine the spatial resolution and the repeatability for this axis.



L = 75 inches (max)

L = 30 inches (min)

Range of motion for L = 75 − 30 = 45 inches

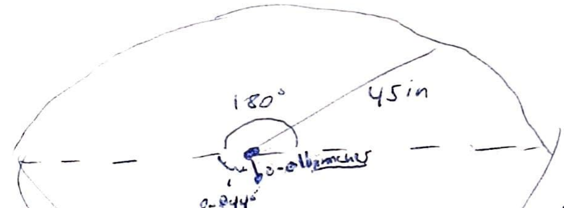
Range of motion for R = 180°

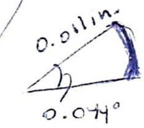
No. of Add. pts = $2^n = 2^{12} = 4{,}096$

a) Control Resolutions:

• For L = Range / 2^n = $\frac{45 \text{ inches}}{4096}$

$\boxed{L = 0.011 \text{ inches}}$





• For R = $\frac{\text{Range}}{2^n} = \frac{180°}{4096}$

$\boxed{R = 0.044°}$ ≈ 0.000768 radians

b) Find Combined Control Res. of R and L axes in linear Scale when telescoping Arm is fully extended and fully retracted. (CR_T)

• use $CR_t = \sqrt{(CR_{\theta L})^2 + (CR_L)^2}$ from $CR_t = (CR_x^2 + CR_y^2 + CR_z^2)^{\frac{1}{2}}$

• use

↳ $CR_{\theta L} = \frac{L \cdot CR_\theta \cdot \pi}{180}$

• $CR_{\theta L}$ (fully extended = 75 in.) = $\frac{(75 \text{ in})(0.044°) \cdot \pi}{180°}$

• $CR_{\theta L}$ = 0.0576 in.

- $CR_{\theta L}$ (fully retracted) $= \dfrac{(30 in.)(0.044°)\cdot\pi}{180°}$
- $CR_{\theta L} = 0.023 in.$

- So CR_t (Fully Extended) $= \sqrt{CR_{\theta L}^2 + CR_L^2}$

$$CR_t = \sqrt{(0.0576 in)^2 + (0.011 in)^2}$$

$$\boxed{CR_t = 0.0586 in.}$$ ← Fully Extended Combined Control Resolution

- So CR_t (fully Retracted) $= \sqrt{CR_{\theta L}^2 + CR_L^2}$

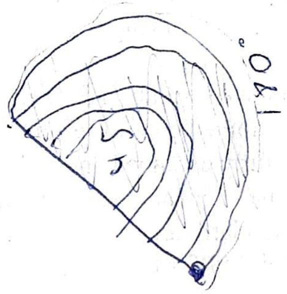
$$CR_t = \sqrt{(0.023 in.)^2 + (0.011 in.)^2}$$

$$\boxed{CR_t = 0.0255 in.}$$ ← Combined Control Resolution of Fully retracted

c.) Determine SR and Repeatability of the L axis.

- $SR = CR +$ mechanical inaccuracies
- $SR = CR + 6\sigma$
- $\sigma = 0.0008$ inches • $CR_L = 0.011$ in.
- $SR_L = CR_L + 6\sigma$
- $SR_L = 0.011\text{ in.} + 6(0.0008\text{ in.})$

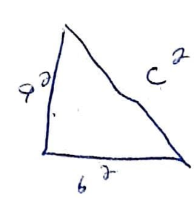
$\boxed{SR_L = 0.0158\text{ in.}}$ ← Solution



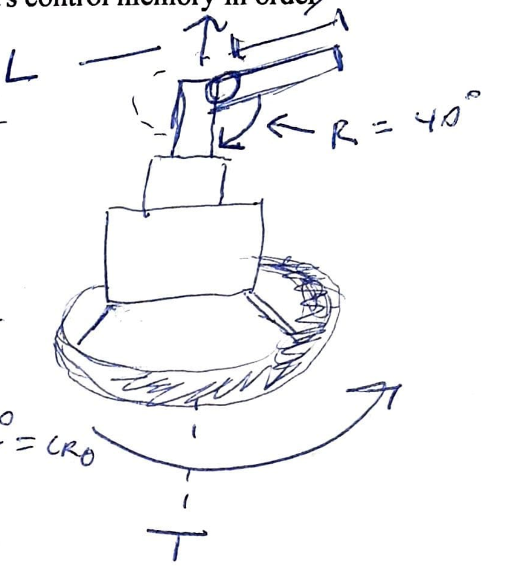
Repeatability $= \pm 3\sigma$

$\text{Rep.}_L = \pm 3(0.0008)$

$\boxed{\text{Rep. } L = \pm 0.0024\text{ in.}}$ ← Solution



6. A TLR robot has a rotational joint (R) whose output link is connected to the wrist assembly. Considering the design of this joint only, the output link is 600 mm long, and the total range of rotation of the joint is 40 degrees. The spatial resolution of this joint is expressed as a linear measure at the wrist and is specified to be 1.0 mm. It is known that the mechanical inaccuracies in the joint have a normal distribution with a standard deviation of 0.006 degrees of rotation. It is assumed that the output link is perfectly rigid so as to cause no additional errors due to deflection.
   a. Determine the minimum number of bits required in the robot's control memory in order to obtain the spatial resolution specified.
   b. Determine the linear repeatability of this axis.



- R-Link = 600 mm
- ~~dR~~ Range = 40°
- SR_R [linear expression] = 1.0 mm
- Mech. Innaccuracies $\sigma = 0.006°$

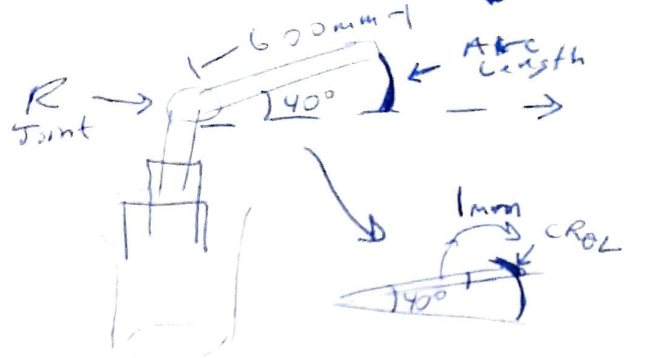
- $CR_{\theta L} = \frac{L \cdot CR_\theta \cdot \pi}{180}$
- $SR = CR + 6\sigma$
- $CR = \frac{Range}{2^n}$
- 2^n = # of add. points
- $\frac{(CR_{\theta L}) \cdot 180}{L \cdot \pi} = CR_\theta$

a.) Det. min # of bits needed to obtain SR specified:

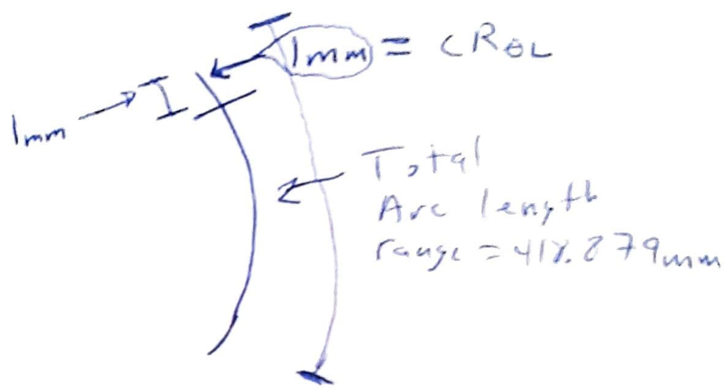
Need to solve for n in $CR = 2^n$; n = # of Add. points = bits

- SR [linear] = 1.0 mm
- $SR[lin.] = CR_{\theta L} + 6\sigma$
- $CR_{\theta L} = SR[lin] - 6\sigma$
- $CR_{\theta L} = 1.00mm - 6\sigma$
- Need to convert $\sigma = 0.006°$ into radians
- $0.006° \Rightarrow \frac{0.006 \cdot \pi}{180} = 0.00010472$ radians $= \sigma$
- Now Find Arc length given link = 600 mm
- Arc length = $r \cdot \theta = 600mm \cdot 0.00010472 = 0.0628 mm$
- $\sigma = 0.0628$
- $CR_{\theta L} = 1.00mm - 0.0628mm = 0.9372mm$
- $CR_{\theta L} = \frac{Range}{2^n} = 0.9372mm \rightarrow Range = 40° = \frac{40 \cdot \pi}{180}$ radians
- Linear Range = Arc Length

- Arc length of 40° with radius = 600mm
- $\left(\frac{40 \cdot \pi}{180} \text{ radians}\right) \cdot 600\text{mm} = 418.879\text{mm}$



- $CR_{\theta L} = 0.9372\text{mm} = \frac{\text{Range}}{2^n}$
- $CR_{\theta L} = 0.9372\text{mm} = \frac{418.879\text{mm}}{2^n}$
- Solve for n.



- $2^n = \frac{418.879\cancel{\text{mm}}}{0.9372\cancel{\text{mm}}}$
- $2^n = 446.947$
- $n = \log_2(446.947)$
- $n = \frac{\log(446.947)}{\log(2)}$
- $n = 8.804$
- need min # of bits, so we must Round up to ensure high enough control resolution; cannot have partial bits.

$\boxed{\text{Solution: } n = \boxed{9 \text{ bits}} \text{ (\# of Add pts) needed}}$

(6.) Determine Linear Repeatability of the R-axis Joint

- Repeatability = $\pm 3\sigma$
- We already calculated linear σ; $\left(\frac{0.006 \cdot \pi}{180}\right)(600\,mm)$

θ radius

arc length $= r\theta$

- $\sigma = 0.006^\circ \rightarrow \sigma_{Linear} = 0.0628\,mm$

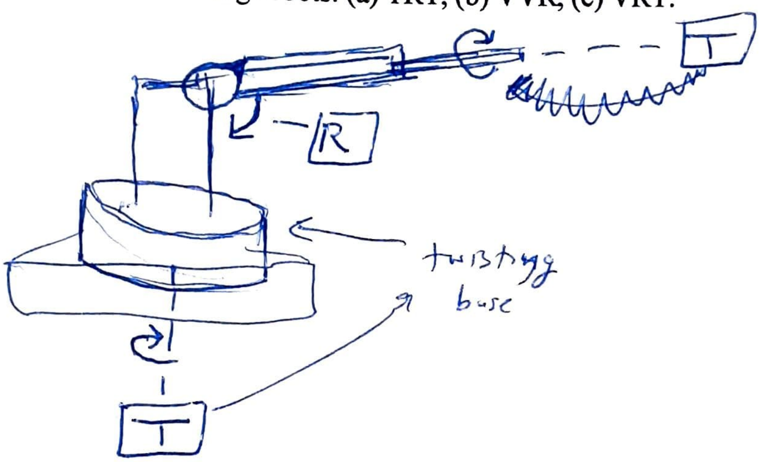
Arc length

- Repeatability $= \pm 3(0.0628\,mm)$

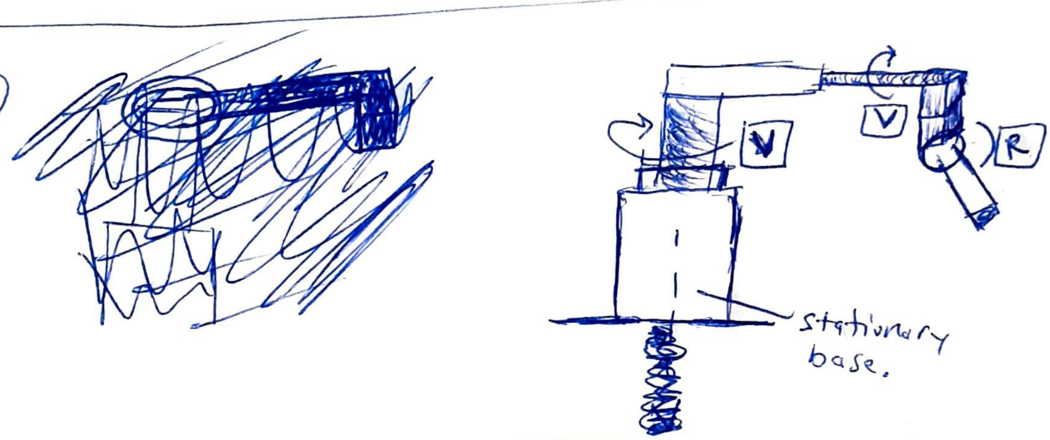
$$\boxed{\text{Repeatability} = \pm 0.1884\,mm}$$

7. Using the notation scheme for defining manipulator configurations, draw diagrams of the following robots: (a) TRT, (b) VVR, (c) VRT.

(a)



(b)



c)