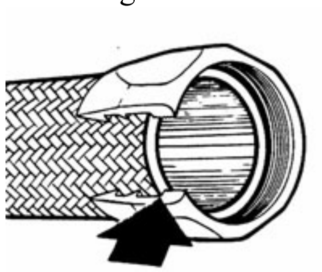
Weekly reports are to be emailed to atbecker@uh.edu by 5:00pm on Tuesdays. The purpose of a weekly report is to: (1) give you text and images for your papers, thesis, and dissertation, (2) document progress, (3) identify if you are stuck or need resources.

# Weekly report

1. **My *Goals* from last week**
   - complete experiment set up
   - 4m experiment (bend and straight)
   - **TA** work

2. **My *Accomplishments* this week**
   - Complete experiment set up
   - 4m bend experiment completed, straight experiment cannot complete because the shaft of motor is broken.
   - Graded ws4~6, and hw1
   - Find braided hose and connector design for SMT experiment set up. After discussing with Michelle, the following two options are doable.
     1. We can design or buy the female connector as figure, and design inner diameter of male connector the to be same as inner diameter of nylon tubing.



     2. The data sheet below is another option for new set up. This braided hose has the same diameter as the tubing we are using now, we can cut off the braided covering on the both side, and insert the inner tubing into our connector.

## TS/TB Series

### Smooth Chemfluor® PTFE Fluoropolymer Smooth Inner Tube
### 304 Stainless Steel High Tensile Strength Braid

hose smooth tube

**applications**

- Sanitary transfer
- Steam transfer core
- Bottle filling
- Gas analysis
- Hydraulic lines
- Extrusion presses
- Molding/Adhesive conveying

**common media**

- Chemicals
- Steam
- Solvents
- Inks and dyes
- Paint
- Injectable materials
- Plastisols

**industry approvals & compliances**

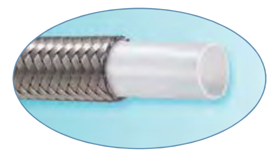
- **FDA approved per 21CFR177.1550 (TS only)**
- **US Pharmacopeia Class VI**

**features & benefits**

- *Greater wall thickness of Chemfluor® PTFE tube*
  - *Up to 33% thicker than most competing products (tube wall .040 minimum)*
  - *Superior kink resistance*
  - *Improved vacuum ratings*
  - *Better damage resistance*
- *Neutral to taste, color and odor*
- *Non-stick, non-contaminating*
- *Cleans easily — steam, detergent or caustic*
- *Can be autoclaved*
- *Full ID sizes*
  - *Greater flow rate per given size*
  - *Less pressure drop through fitting area than hoses with tube size ID*

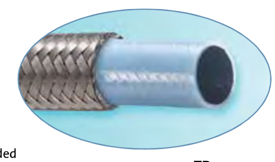
**details**

**TS Series construction**
- *Inner Tube:* White Chemfluor® PTFE
- *Reinforcement:*
  - 304 stainless steel braid
  - 1-1/2" ID size double-braided for added kink resistance, higher pressure rating; working pressure based on minimum 4:1 safety factor; burst to suggested maximum working pressure



TS

**TB Series construction**
- *Inner Tube:* Black Chemfluor® PTFE
  - Electrostatic dissipating conductive version of TS Series
- *Reinforcement:*
  - 304 stainless steel braided
  - 1-1/2" ID size double-braid for added flexibility, higher pressure rating; working pressure based on minimum 4:1 safety factor; burst to suggested maximum working pressure



TB

**fittings**
- PermaSeal® crimp-style
  - Over 40 styles in a wide range of materials
  - Standard: 316L stainless steel (wetted surfaces)

**engineering specifications**

**average length**

| | |
|---|---|
| 1/8" | 50' |
| 1/4" | 125' |
| 3/8" | 75' |
| 1/2" | 125' |
| 3/4" | 40' |
| 1" | 30' |
| 1-1/2" | 30' |

**minimum overall length of hose assemblies with anti-kink casing**

1/4" size – 18" OAL
3/8" and 1/2" sizes – 24" OAL

**temperature rating**

- -100°F to +450°F continuous; 500°F intermittent
- -73°C to +232°C continuous; 260°C intermittent

**TS/TB/TD/TDB Series hose specifications**

| Part Number | Inside Diameter | | Outside Diameter | | Maximum Working Pressure | | Minimum Burst Pressure | | Minimum Bend Radius | | Vacuum Hg @ 70°F | | Weight | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | in. | mm | in. | mm | PSI | MPa | PSI | MPa | in. | mm | in. | mm | lb./ft. | kg/m |
| 2TS | 1/8 | 3.2 | 1/4 | 6.1 | 3,000 | 20.69 | 15,000 | 103.43 | 1.50 | 38.10 | 29.9 | 760 | 0.05 | 0.07 |
| 4TS/TB | 1/4 | 6.4 | 3/8 | 9.7 | 3,000 | 20.69 | 13,500 | 93.08 | 2.50 | 63.50 | 29.9 | 760 | 0.08 | 0.12 |
| 6TS/TB | 3/8 | 9.5 | 1/2 | 13.2 | 2,500 | 17.24 | 10,000 | 68.95 | 3.50 | 88.90 | 29.9 | 760 | 0.12 | 0.18 |
| 8TS/TB | 1/2 | 12.4 | 5/8 | 16.8 | 2,000 | 13.79 | 8,500 | 58.61 | 4.00 | 101.60 | 29.9 | 760 | 0.15 | 0.22 |
| 12TS/TB | 3/4 | 19.1 | 7/8 | 22.4 | 1,200 | 8.27 | 4,800 | 33.10 | 7.50 | 190.50 | 29.9 | 760 | 0.22 | 0.33 |
| 16TS/TB | 1 | 25.4 | 1-1/8 | 29.5 | 800 | 5.51 | 3,200 | 22.06 | 12.00 | 304.60 | 20.0 | 508 | 0.31 | 0.46 |
| 24TD/TDB | 1-1/2 | 38.1 | 1-3/4 | 44.2 | 900 | 6.21 | 4,000 | 27.58 | 15.00 | 381.00 | 15.0 | 381 | 0.44 | 0.66 |

**Important:**

**Burst pressure** ratings at ambient 70°F (21°C). See applicable notes below on vacuum/pressure ratings at temperatures other than ambient.

**Working Pressure** is given @ 70°F; Decrease working pressure 1% for every 2°F above 350°F.

**Vacuum Rating** is given @ 70°F; Decrease vacuum rating 1% for every 2°F above 350°F. 1-1/2" size (TD, TDB) vacuum rating decreases when installed less than 2X min. bend radius.

**Extended Service Life Tip:** All 3/4", 1", and 1-1/2" TS/TB/TD/TDB assemblies 36" and longer are strongly recommended to use full-length anti-kink casing (see Hose Cover Options section, pages 79–80) to help prevent potential kinking and/or liner vacuum collapse.

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- Writing "control study of 1 DOF actuated by solid Media Transmission" draft for IROS. After talked with DR. Tsekos on Tuesday, we can write a paper for IROS about 1DOF SMT control study, including SMT mechanism, 1m open loop control, 1m closed loop PID control, system delay, system response, system tolerance. For now, the abstract and introduction is finished.

# Control study of 1 DOF robot actuated by Solid Media Transmission

Haoran Zhao, Xin Liu, Aaron T. Becker and Nikolaos V. Tsekos

***Abstract*— Solid-media transmission (SMT) is a new positioning manipulator for MRI-guided intervention which must be MRI-compatible. The SMT is used as a positioning manipulator because it is MRI compatible, and has similar characteristics to pneumatic and hydraulic transmissions. SMT uses tubes as conduits for remotely force transmission, but uses solid spheres and spacers inside the conduits rather than fluids or air to transfer and control the displacement in order to avoid leakage issues. The stiffness of SMT enables fast position control and higher displacement resolution. This paper analyzes the system characteristics of the solid media transmission (SMT) system build by nylon materials and 1 DOF robot. The characteristics study starts from 1 DOF open loop to 1 DOF closed loop. The SMT model is nonlinear mainly because of friction between the solid media and tubing, also the 1 DOF manipulator. The flexible tubing elasticity deformation, and backlash due to sphere and spacer packing process. However, according the experiment data, we can find the instinct characteristics of SMT system, including delay, system error tolerance, etc.**

## I. Introduction

Since 1987s many publications demonstrated that the Minimally invasive surgery (MIS) can reduce the damage of surgeons by decreasing all of the followings: blood loss, postoperative pain, postoperative complication, surgical time and length of hospital stay. However, the MIS need to be performed using medical imaging guidance. Magnetic resonance imaging (MRI) is a promising technique for imaging guided interventions (IGI) because of its broad applicability, noninvasive nature, and ionizing-radiation-free operation [**?**].Although MRI has many benefits to offer, the main challenge is that the MRI operation requires high strength magnetic fields which impose significant limitation of instruments selection used in MRI room. and the MRI instinct geometric constraints limit the operating space as the patients must be placed in the cylindrical bore.

To address these limitations of MRI guided interventions, the MRI compatible robotic systems are being developed. The robot actuators must work in the presence of 1 to 3 Tesla magnetic fields and rapidly switching magnetic field gradients without causing imaging artifacts from operating motors during MRI scanning [**?**]. by using teleoperation robots, the MIS can be controlled from outside of the MIR bore or from MRI control room. Thus, force transmission systems play an important role in the teleoperation robotic system. In such MRI compatible robotic systems, investigators have investigated several mechanical drive systems, such as cables, belts, driveshafts, and parallel structures []. But all these mechanical dive systems require rigid frame structures and cannot rotate or adjust freely based on the specific situation or clinical procedures.

The most common MR compatible transmission system is fluid power system. Both pneumatics and hydraulics are applications of fluid power transmission systems. Fluid systems are intrinsically MR compatible without electromagnetic interference made of non magnetic materials. However, the fluidic equipments are complex and expensive, also the leakage is a significant concern. In order to construct a simple, low cost, MR compatible transmission system, we propose a novel actuation mechanism termed solid media transmission (SMT). SMT resembles fluidic actuators but has tubing filled with solid media, spheres and spacers. In the earlier work, we describe a system assembled by stepper motor and record data by sensor unit [**?**]. However, stepper motor has several disadvantages such as low efficiency, low accuracy, and no feedback to indicate missed steps. additional, the oscillation of force transmission is caused by the low quality design of sensor unit. In the new set up, we change stepper motor to servo motor in oder to supply continuous and stable input, also execute high performance closed loop control.The new 1 DOF robot can not only directly present output data and dynamic process, but also benefits SMT system analysis and control study.

This paper is organized as follows: In section II, we describe the theoretical basis of SMT mechanism. Section III presents experiment set up and positioning performance of open loop SMT control. Section IV presents closed loop PID SMT control and output results with step, ramp, chirp signal as input. Finally, in section V, we conclude and discuss the experiment results, outline future work.

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## II. SOLID MEDIA TRANSMISSION MECHANISM

SMT mechanism is composed of many solid, discrete media packing inside a tubing. those solid media form continuous units transferring force to actuator. To promise those solid media can freely move in the tubing, there are following two properties: 1) the solid sphere diameter ($D_{\text{sphere}}$) should be less than inner tubing diameter ($ID_{\text{tube}}$). To avoid more than one sphere in cross section, the relationship between $D_{\text{sphere}}$ and $ID_{\text{tube}}$ is:

$$1 \leq \frac{ID_{\text{tube}}}{D_{\text{sphere}}} \leq 1 + \frac{\sqrt{3}}{2} \qquad (1)$$

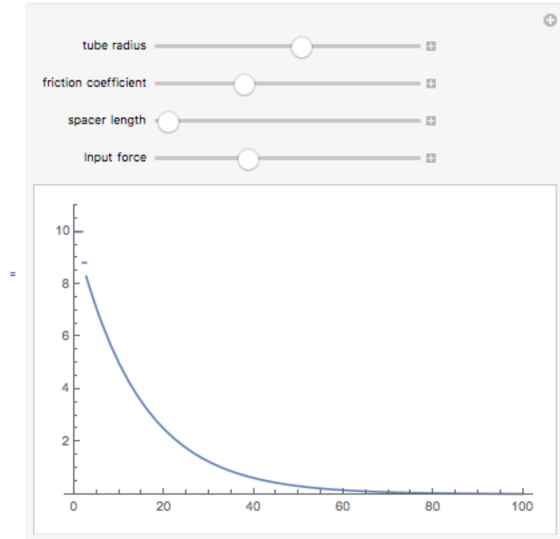
2) considering bending set up for specific situation, the radius of spacer between two spheres cannot be random size. it needs to be based on the bending radius ($R_{\text{bend}}$), spacer length ($L_{\text{spacer}}$), and $ID_{\text{tube}}$ :

- Relationship between output force and input force, math is following:

f[ID_, D_, l_, F_, μ_, L_] :=

$$\begin{cases} F & \text{Floor}\left[\frac{L}{\sqrt{2D(l+ID)+l^2-ID^2}}\right] < 2 \;||\; ID == D \text{ (*1 sphere*)} \\ F\left(1-2\mu\frac{ID-D}{\sqrt{2D(l+ID)+l^2-ID^2}}\right) & \text{Floor}\left[\frac{L}{\sqrt{2D(l+ID)+l^2-ID^2}}\right] == 2 \;\&\&\; ID > D \text{ (*2 sphere*)} \\ F\left(1-2\mu\frac{ID-D}{\sqrt{2D(l+ID)+l^2-ID^2}}\right)\left(1-\mu\frac{ID-D}{\sqrt{2D(l+ID)+l^2-ID^2}}\right)^{\frac{L}{\sqrt{2D(l+ID)+l^2-ID^2}}-2} & \text{Floor}\left[\frac{L}{\sqrt{2D(l+ID)+l^2-ID^2}}\right] > 2 \;\&\&\; ID > D \text{ (*number of sphere>2*)} \end{cases};$$

(*Function that takes as input ID: tube diameter, D: sphere radius ,l:spacer length and F: Input force, μ:friction parameter and returns f: force output*)




**3. My *Goals* for next week**

- Analysis the data of 1m open and closed loop control
- Complete draft
- TA work

**4. What I need Dr. Becker to do:**