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A two-class rotation transmission nanobearing driven by gigahertz rotary nanomotor

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ABSTRACT

For a vehicle, its speed can be adjusted via a transmission system. In this study, we propose a model of two-class rotation transmission nanosystem to adjust the input rotation via a gigahertz rotary nanomotor. To obtain an efficient rotation transmission system, carbon nanotubes, which have super-high in-shell strength but extremely low inter-shell friction, are adopted to build the coaxially rotary components. Besides 200 GHz motor, the other two components are the rotor1 in the class-1 nanobearing, and the rotor2 in the class-2 bearing, respectively. Considering both the chirality and radii differences of the rotary components, 27 types of transmission models are built and tested via molecular dynamic simulations. When the transmission ratio of the rotational frequency of the rotor2 and the input frequency is between 0.1 and 0.9, a successful transmission system is obtained. According to the rotation transmission ratios (RTRs) of both rotors in each model, some conclusions are drawn for potential design of such nanodevice. Besides, temperature can also influence the output rotation of the rotor2. It implies another way to adjust the output rotation from the same transmission system.

1. Introduction

It is well known that the in-plane strength of graphene [1] is extremely high, ~130 GPa [2], and the inter-plane friction is slight. The reason is that the in-plane strength is determined by the strength of 2sp^2-2sp^2 covalent bonds. And the inter-plane interaction during relative sliding between neighbor graphene layers mainly depends on the repulsion of delocalized π electrons of the carbon atoms. Carbon nanotube (CNT) [3], a type of one-dimensional carbon material, behaves similarly with graphene, i.e., very high in-shell strength but extremely low friction between neighbor shells [4–6]. With consideration of the two excellent mechanical properties, i.e., Carbon nanotubes are popular in design of nanodevices, such as, nanooscillator [7–10], nanobearing [11–14], nanomotor [15–23], etc.

For a rotary nanomotor, it can play as an engine to drive some nanodevices like machines [24]. The rotational frequency of the nanomotor is commonly beyond the requirement of the device. When the rotational frequency of the nanomotor is difficult to adjust directly, people have to introduce an extra component to meet the requirement. To obtain a specified rotational frequency from the nanomotor, like a transmission system in a car, a nanosystem is needed to transfer the input rotation from the nanomotor to the given output rotation. In 2015, Cai et al. [25,26] proposed the concept of rotation transmission system from carbon nanotubes to transfer both the magnitude and direction of the motor's rotation. In their model, a rotary CNT motor coaxially laid with a CNT nanobearing form into a nanosystem for rotation transmission. The rotor in the bearing is driven to rotate by the nanomotor via the interaction at their adjacent edges. Their results demonstrate that the output rotational frequency of the rotor in the nanobearing has large amplitude fluctuation when the bearing is made from armchair CNTs. Sudden drop of the output rotation happens frequently. Even using zigzag CNTs as the nanobearing, the output rotation still has obvious fluctuation. The reason is that the rotor in the bearing has degree of freedom along axial direction, and can oscillate during rotating. During oscillation, the gap between the neighbor edges of the motor and the rotor varies with time, and the interaction between them is not stable. This is the reason for the fluctuation of the rotor's rotational frequency.

To overcome the difficulty, and to obtain a frequency-reducing transmission system, in the present study, we introduce two-class rotation transmission system from carbon nanotubes as shown in Fig. 1. Comparing to the models in reference [25], the present model has two coaxial nanobearings, i.e., class-1 and class-2 bearings. The motion of rotor1 is constrained by more components, including both L-stators, the right edge of the motor, the R-stator1, and the rotor2. Hence, the oscillation of the rotor1 happens difficultly. To show the feasibility and

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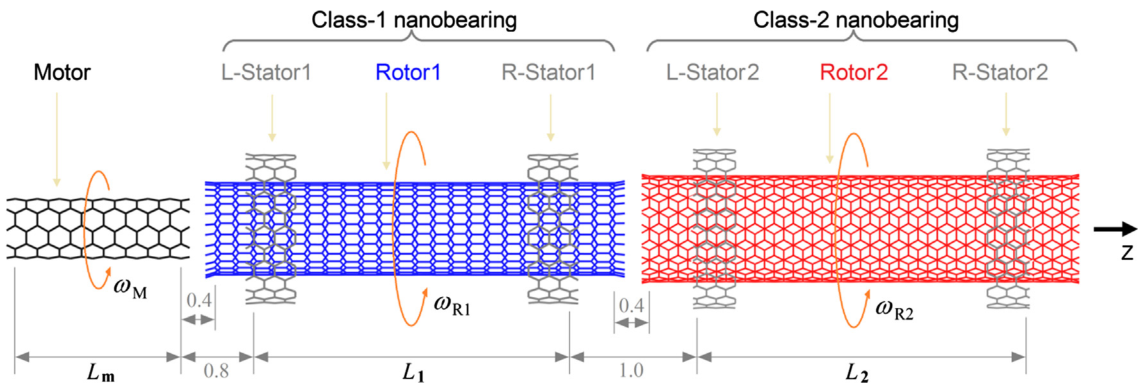

Fig. 1. Schematic of a two-class rotation transmission system (TCRTS) made from carbon nanotubes. It contains a motor with input rotation and two bearings from DWNTs (e.g., (5,5)/(10,10) with (5,5) as rotor and (10,10) as stators). All tube axes are aligned and all external ends of tubes are hydrogenated. The initial gap between the motor and the rotor1, or between both rotors, is 0.4 nm. Other geometric parameters of the system are listed in Tables 1 and 2. ω_M is the input rotational frequency of the motor. ω_{R1} and ω_{R2} are the output rotational frequencies of the rotor1 and the rotor2, respectively.

Table 1
Radii and lengths of CNTs as rotors in TCRTS involved in simulations. Dimension unit: nm.

CNT	(8,0)	(5,5)	(9,0)	(14,0)	(16,0)	(17,0)	(10,10)	(18,0)	(13,13)	(15,15)	(18,18)
Radius	0.313	0.339	0.353	0.548	0.627	0.665	0.678	0.703	0.881	1.017	1.221
Length	7.952	7.993	7.952	8.165			7.993		7.993		

Table 2
Geometric parameters of the 27 different TCRTS models involved in simulations.

(a) Both motor and rotor 1 from the same CNT. DWNTs (5,5)/(10, 10), (8,0)/(17,0), and (14,0)/(13,13) as bearings

Model No.	1	2	3	4	5	6	7	8	9
Motor	(5,5)	(5,5)	(5,5)	(8,0)	(8,0)	(8,0)	(14,0)	(14,0)	(14,0)
Rotor1	(5,5)	(5,5)	(5,5)	(8,0)	(8,0)	(8,0)	(14,0)	(14,0)	(14,0)
Rotor2	(5,5)	(8,0)	(14,0)	(5,5)	(8,0)	(14,0)	(5,5)	(8,0)	(14,0)
L_1/nm	7.225	7.193	7.193	7.152	7.152	7.152	7.365	7.365	7.365
L_2/nm	6.302	6.302	6.301	6.302	6.302	6.302	6.302	6.302	6.301
L_m/nm	3.074	3.074	3.074	2.840	2.840	2.840	3.053	3.053	3.053

(b) Both motor and rotor 2 from the same CNT. DWNTs (5,5)/(10, 10), (8,0)/(17,0), (9,0)/(18,0) and (14,0)/(13,13) as bearings

Model No.	10	11	12	13	14	15	16	17	18
Motor	(5,5)	(5,5)	(5,5)	(8,0)	(8,0)	(8,0)	(14,0)	(14,0)	(14,0)
Rotor1	(8,0)	(9,0)	(14,0)	(5,5)	(9,0)	(14,0)	(5,5)	(8,0)	(9,0)
Rotor2	(5,5)	(5,5)	(5,5)	(8,0)	(8,0)	(8, 0)	(14,0)	(14,0)	(14,0)
L_1/nm	7.152	7.152	7.365	7.194	7.152	7.365	7.193	7.152	7.152
L_2/nm	6.302	6.302	6.302	6.302	6.302	6.302	6.302	6.302	6.302
L_m/nm	3.074	3.074	3.074	2.840	2.840	2.840	3.053	3.053	3.053

(c) The motor, and both rotors are made from different CNTs

Model No.	19	20	21	22	23	24	25	26	27
Motor	(5,5)	(5,5)	(9,0)	(9,0)	(14,0)	(14,0)	(5,5)	(5,5)	(10,10)
Rotor1	(9,0)	(14,0)	(5,5)	(14,0)	(5,5)	(9,0)	(10,10)	(13,13)	(5,5)
Stator1	(18,0)	(13,13)	(10,10)	(13,13)	(10,10)	(18,0)	(15,15)	(18,18)	(10,10)
Rotor2	(14,0)	(9,0)	(14,0)	(5,5)	(9,0)	(5,5)	(13,13)	(10,10)	(13,13)
Stator2	(13,13)	(16,0)	(13,13)	(10,10)	(18,0)	(10,10)	(18,18)	(15,15)	(18,18)
L_1/nm	7.152	7.365	7.194	7.365	7.193	7.152	7.193	7.194	7.193
L_2/nm	6.302	6.302	6.302	6.302	6.302	6.302	6.302	6.302	6.302
L_m/nm	3.074	3.074	2.840	2.840	3.053	3.053	3.074	3.074	3.074

efficiency of rotation transmission, in this study, the input rotational frequency is set to be 200 GHz. Three other factors are considered in simulation. The first factor is the chirality of nanotubes in the rotary components. Besides, the radii difference is also considered. Detailed parameters are given in Table 1. The second factor is the layout of the nanotubes in the three components. Detailed schemes are listed in Table 2, and supporting materials. The final factor is the temperature of system. At higher temperature, the vibration of atoms in tubes is more drastic, and the interaction between neighbor edges of motor and rotors varies greater. Discussion on the dynamics response of the systems is in Section 3.

2. Model and methodology

2.1. Model of a two-class rotation transmission system

Fig. 1 gives the schematic of a two-class rotation transmission system. The components are made from CNTs. The parameters of the