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ภาคผนวก ก

ตารางแสดงค่าข้อมูล

ตารางที่ ก.1 ค่า Reaction Force (RF) ในแนวแกน Y

| Node	RF (Y)	Node	RF (Y)	Node	RF (Y)	Node	RF (Y)	Node	RF (Y)
1	62756.2	21	43661.7	41	-3957.82	61	-21308.3	81	-115636
2	138772	22	39284.6	42	-6133.55	62	-4385.24	82	-115880
3	101322	23	35553.4	43	-7457.33	63	-19782.8	83	-170458
4	140875	24	31770.2	44	-9872.85	64	-5310.19	84	-161799
5	163897	25	28653.6	45	-11232.7	65	-20580.3	85	-380838
6	146396	26	25393.5	46	-13875.6	66	-8149.91	86	-521788
7	147571	27	22772.9	47	-15308.1	67	-22608.3		
8	134193	28	19955.5	48	-17995.1	68	-10020.5	Sum+	2378188.3
9	130479	29	17728.1	49	-19570.6	69	-24629.5	Sum-	-2378190.4
10	118203	30	15268	50	-21782.3	70	-10416.2		
11	109830	31	13346.1	51	-23667.5	71	-26269		
12	100436	32	11156.3	52	-24331.6	72	-11209.9		
13	92232.5	33	9465.25	53	-26919.7	73	-26667.1		
14	84560.9	34	7458.42	54	-24326.3	74	-12854.3		
15	77194.3	35	5934.68	55	-28407.7	75	-19772.4		
16	70621.6	36	4022.39	56	-20735.1	76	-23014.7		
17	64273.5	37	2611.45	57	-27470.9	77	-52796		
18	58527.5	38	702.715	58	-14181.7	78	-66781.8		
19	53169.8	39	-641.955	59	-24517.2	79	-84151.6		
20	48139.2	40	-2640.12	60	-7627.27	80	-88430.4		

- **Sum+** คือ ผลรวม RF ทิศทางบวก Y   - **Sum-** คือ ผลรวม RF ทิศทางลบ Y

ตารางที่ ก.2 ค่าแรงกดของสกรูของรูปแบบการขันก่อนและหลังการทดสอบ

Screw No./Model	Contact normal force (N)								Applied Bolt Load (N)	
	Before Test				After Test					
	6 kgf.cm		7 kgf.cm		6 kgf.cm		7 kgf.cm		6 kgf.cm	7 kgf.cm
	Circular	Across	Circular	Across	Circular	Across	Circular	Across		
1	1946.73	1945.24	1946.73	1945.85	1942.27	1938.76	1941.79	1936.00	1946.00	1946.73
2	991.32	990.48	1155.89	1155.59	983.88	982.67	1147.44	1146.57	990.57	1155.67
3	989.95	990.52	1154.10	1155.64	978.63	978.28	1143.02	1143.17	990.57	1155.67
4	1192.48	1194.31	1391.32	1392.37	1090.04	1092.09	1274.35	1277.07	1192.60	1391.37
5	1170.20	1192.28	1367.81	1391.62	997.49	1006.00	1183.34	1188.40	1192.60	1391.37
6	1589.87	1590.13	1589.94	1590.13	1520.15	1519.46	1521.51	1519.29	1590.13	1590.13
7	1182.24	1191.49	1377.00	1390.14	1048.98	1054.69	1232.42	1238.83	1192.60	1391.37
8	1183.18	1192.24	1378.64	1390.77	1003.57	1004.86	1175.46	1176.50	1192.60	1391.37
9	1192.12	1186.45	1391.26	1385.42	1044.80	1044.12	1233.51	1233.32	1192.60	1391.37
10	1459.62	1459.80	1703.16	1703.18	1454.94	1455.04	1696.87	1696.98	1460.05	1703.39

ภาคผนวก ข

ผลงานที่ได้รับการตีพิมพ์
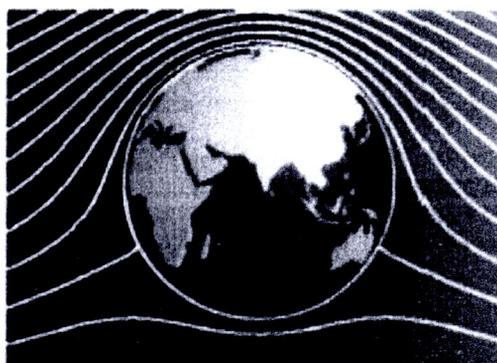
TSME - ICOME
1st International Conference on Mechanical Engineering

October 20th - 22nd, 2010 Sunee Grand Hotel,
Ubon Ratchathani, Thailand

Conference Program

รูปที่ ข.1 ใบปิดหน้างานสัมมนาวิชาการ

The First TSME International Conference on Mechanical Engineering

Study of Screw Tightening Sequence on the Looseness
of the Top Cover in the Hard Disk Drive Assembly

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Abstract

In hard disk drive (HDD) assembly process, the top cover is attached to the base assembly via screws. Screw tightening sequence could result in looseness of previously fastened screws and thus rework of the process. The current work focuses on the study of behavior and effects of screw tightening sequences to the screw looseness by using nonlinear finite element method. The three-dimensional 3.5-inch HDD assembly including top cover, base, rubber seal and screws are modeled and analyzed. It can be concluded that the later sequences of screw tightening affect the looseness of the previously fastened screws to some extent. Higher lose of tightening torque is observed at the screws located near the currently tightened screw. Alteration of the screw fastening sequence as well as the applied torques can reduce the looseness and therefore prevent the top cover slip.

Keywords: Screw looseness, Hard disk drive, Tightening sequence, Finite element analysis

1. Introduction

In hard disk drive (HDD) manufacturing process, the screw fastening procedure to attach the top cover to the base of the HDD consists of applying some specified pre-torque to all the screws to preliminarily fasten the top cover to the base and final screw fastening with a larger torque so that the top cover is tightly secured the base. However, looseness of the top cover is occasionally observed as the loosening torque of some screws is detected to be as low as half of the applied torques. The disk must then be returned to rework the screw fastening procedure which increases the cost and time in manufacturing process. However, screw fastening using too much tightening torque may lead to deformations of the top cover or chipping of the material between the contact surfaces that cause contamination. This study aims to use Finite Element Analysis (FEA) to investigate the effects of changing the screw tightening sequence on the deformations of the top cover and the screw loosening torque.

Montgomery [1] studied the influences of boundary conditions on the shank stress in 3D solid bolt to decrease run-time in finite element
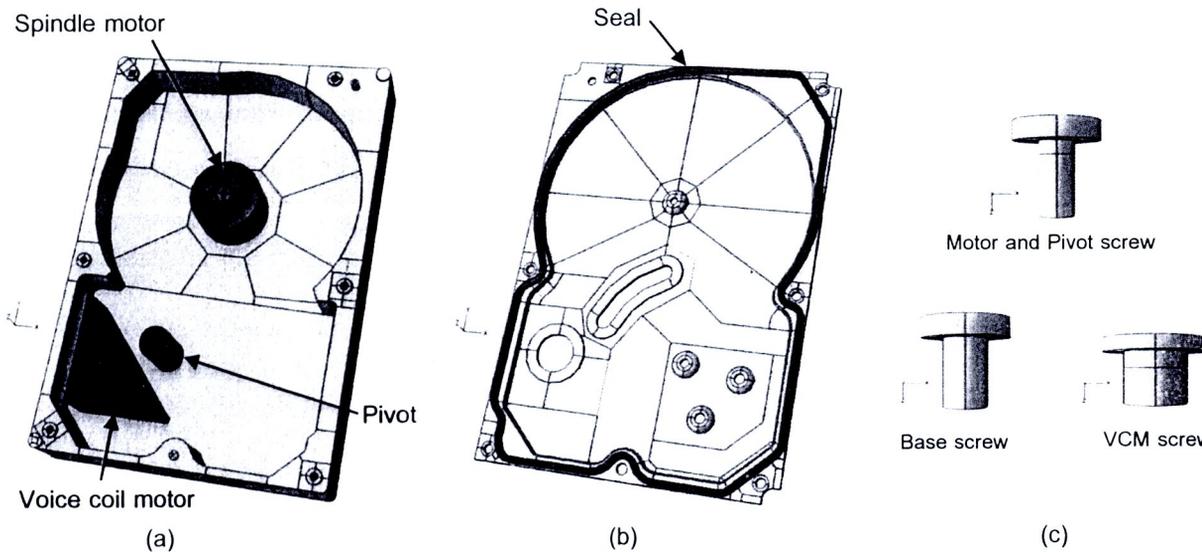
Fig.1 The parts of HDD model (a) base (b) top cover (c) screw.

method. It was shown that the use of smear contact at the thread region creating the same stress distribution as the exercise of thread modeling. Application of tied contact provides a slightly higher stress in the vicinity of the thread. However, results from both types of contacts are comparable at some distance from the thread. Wierszycki [2] analyzed the screw loosening and fatigue of a three dimensional dental implant model for problems caused by mechanical reason. Izumi [3] found that the loosening due to shear loading is initiated when complete thread slip is achieved prior to bolt-head slip.

The current research examines the effects of screw tightening sequence of a 3.5-inch HDD assembly to the top cover screw looseness by using a commercial finite element analysis program, ABAQUS [4]. A nonlinear analysis is performed for two cases, herein defined as Model I and Model II. In Model I, all screws are simultaneously

tightened while screw tightening sequence is specified in Model II. Displacements of the top cover and the screw loosening torques are compared and discussed.

2. Modeling and Analysis

The 3.5-inch HDD model employed in the present analysis is shown in Fig. 1. The model consists of the base, the top cover, and the screws. To simulate the rigid parts of the assembly, the spindle motor, pivot and voice coil motor are attached to the base model. Ten screws are used in the HDD assembly. They are numbered according to the tightening sequence as illustrated in Fig. 2.

Six screws, S4 to S9, fasten the top cover and the base together. The screws S2 and S3 assemble the top cover to the voice coil motor. The screws S1 and S10 are used to fix the top cover to the spindle motor and the pivot, respectively. A rubber seal beneath the top cover is used to prevent leakage of the air inside the assembly chamber. In Model II, screws S1 to

S9, are fastened consecutively. After that, screws S2, S3, S4 and S9 are re-tightened with the same torque and a higher torque is applied to screws S1 and S6. Then, screw S10 is fastened at the final step.

2.1 Boundary Conditions and Contact Surfaces

During the screw tightening process, the assembly is put in a slot and clamped on both the left and the right sides. In the analysis, the boundary conditions are thus specified as fixed at the bottom, and on the left and the right surfaces as shown in Fig. 2. The contact surfaces between the screw head and the top cover is set as frictional contacts with the friction coefficient of 0.15. The contact surface between the base and the rubber seal on the top cover are set frictionless. The interactions between the screw thread regions and the base are assigned as tied contact.

2.2. Material Properties

The base of HDD is made of aluminum alloy ADC12. The top cover and the screws are stainless steel SUS XM7. The seal is made of rubber. The properties of the materials used in the simulation are listed in Table. 1.

2.3 Meshing

Meshing of the FE model is shown in Fig. 3. Meshing is refined at the contact areas, especially those between the screws and other parts. The element type used in the analysis is a three-dimensional 8-node stress element. The element shapes are mixed between hexahedral and tetrahedral elements.

2.4 Loading Conditions and Analysis Steps

In the tightening process, the tightening torque applied to the screws S1 and S6 is 8 kgf.cm and the torque for other screws is 6 kgf.cm. To simplify the analysis, the tightening torque is changed to a bolt load applied to the partition between the head and the shank of the screw. The applied bolt load, P, is calculated from [5]

$$P = \frac{T}{Kd} \qquad (1)$$

where T is the tightening torque, d is the screw diameter, and K is the torque coefficient obtained as

$$K = \left(\frac{d_m}{2d}\right)\left(\frac{\tan \lambda + f \sec \alpha}{1 + f \tan \lambda \sec \alpha}\right) + 0.625 f_c \qquad (2)$$

The parameter d_m is the average screw diameter, λ is the screw lead angle, α is the thread angle, f is friction coefficient of the thread and f_c is friction coefficient of the bearing.
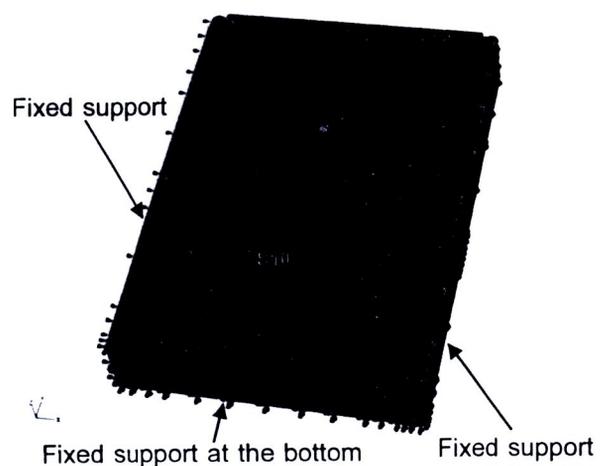

Fixed support

Fixed support at the bottom   Fixed support

Fig. 2 Three-dimensional 3.5-inch HDD model

Table. 1 Mechanical properties of materials

Properties	SUS XM7	ADC12	Rubber
Density (g/cm^3)	8.00	2.70	1.50
Modulus of Elasticity (GPa)	193.00	69.16	2.14
Poisson's ratio	0.30	0.33	0.44

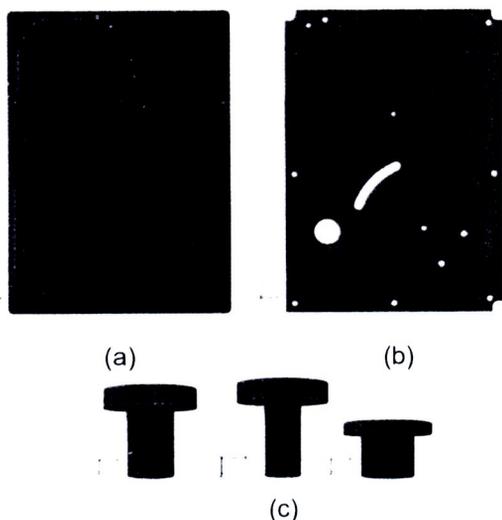(a)   (b)

(c)

Fig.3 Meshing of the FE model (a) base (b) top cover (c) screws

For example, for a screw with diameter 2.5 mm and d_m of 2.2565 mm, λ is 3.632°, α is 60°, and f and f_c are 0.15. Therefore, the value of the torque coefficient K, from Eq. (2), is equal to 0.1973. When the screw is subjected to a tightening torque of 6 kgf.cm, the bolt load P computed from Eq. (1) is 1193 N. Parameters for all screws in the HDD assembly as well as the applied tightening torque are listed in Table. 2. In the analysis of Model I, all bolt loads are applied to the screws at the same analysis step to simulate the concurrent fastening of all screws. For Model II, the corresponding bolt loads are applied in a consecutive order from S1 to S10.
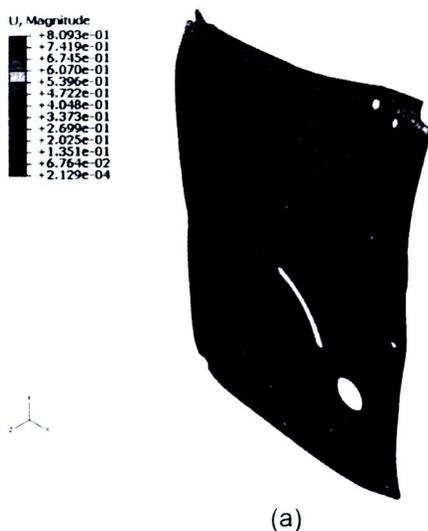
3. Results and Discussions

The deformed shapes and the displacement magnitude of the top cover for both models are shown in Fig. 4. It can be seen that the deformed shapes of the top cover from the two models are similar. Displacement in the negative z-direction is observed in the neighborhood of all tightened screws.

Table.2 Bolt loads applied to the screw model

Screw number	Diameter (mm)	Applied torque (kgf.cm)	Bolt load (N)
S1	2	8	1947
S2, S3	3	6	991
S4, S5, S7-S9	2.5	6	1193
S6	2.5	8	1590
S10	2	6	1460

(a)

TSME - ICOME

U, Magnitude
+8.088e-01
+7.414e-01
+6.741e-01
+6.067e-01
+5.394e-01
+4.720e-01
+4.047e-01
+3.373e-01
+2.700e-01
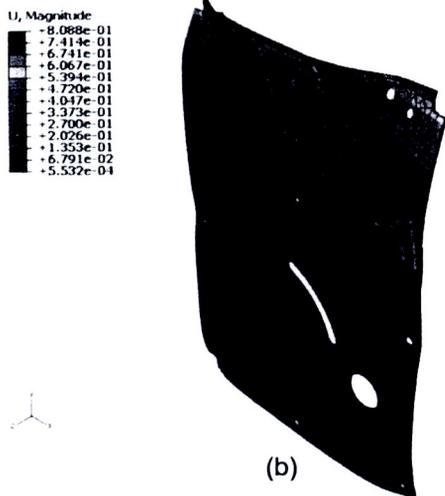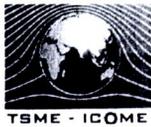+2.026e-01
+1.353e-01
+6.791e-02
+5.532e-04

(b)

Fig. 4 The deformed shapes and displacements of the top cover (magnified 10 times) for (a) Model I (b) Model II

A smaller displacement occurs in the middle area of the top cover where there are rigid supports of spindle motor, voice coil motor and pivot. A larger displacement takes place around the top cover edges due to the rubber seal deformation from a compression transferred from bolt loads applied at the screws. The maximum displacement occurring near the screw S6 (at the top right corner of the top cover) is noticeably larger than those of the other parts.

The contact normal force distributions of all screw heads from both models are also examined. For the screws located in the middle of the HDD, S1, S2, S3 and S10, the highest contact normal force is near the shank and decreases as the distance from the shank increases. An example of the contact normal force distribution at the screw head S1 is illustrated in Fig. 5 (a). For screw S4 to S9 located along the edges of the HDD

assembly, the contact normal force distributions are not as uniform. High contact normal forces are noticed only at the rims of the screws and a higher contact force is detected on the side near the rubber seal support as shown in Fig. 5 (b).

The screw looseness of Model I and II are examined by the change of the summation of all the contact normal force at the contact areas between the top cover and the screw head. For Model I, the total contact forces at all screw heads are the same as the applied bolt loads as expected. Lower contact forces at the screw heads which indicate the screw looseness can be noticed in Model II. In Model II, the contact force at the screw head arises as the bolt load is applied to the screw. Contact forces of the screws previously fastened are also affected by the screw that is tightened in the current step. In general, the contact forces of the screws close to the current one decrease as the top cover is pressed toward the base. The contact forces of the screws farther away from the current screw are mostly increased due to bouncing of the top cover.

An example of the change in contact forces at the screw heads for step 8 (tightening of screw S8), step 9 (tightening of screw S9) and step 10 (re-tightening of screw S2) is shown in Fig.6. When the contact forces of step 8 and 9 are compared, a decrease in contact forces of screws in the vicinity of S9, i.e., S2, S3, S4 and S8 is perceived. A slight increase in contact forces for the other screws can also be noticed.
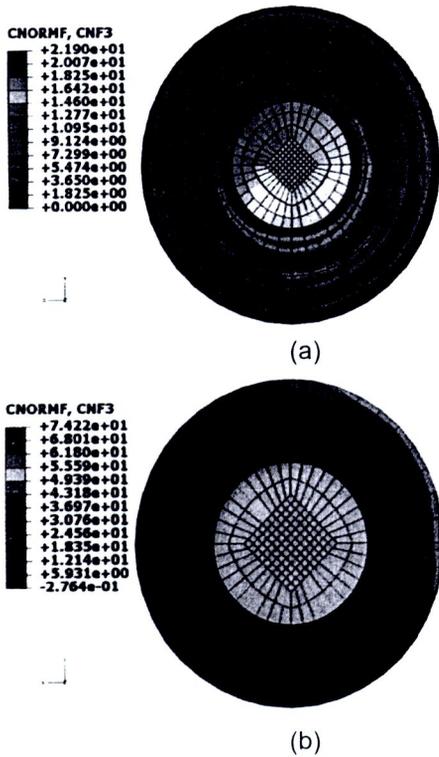
TSME - ICOME

CNORMF, CNF3
+2.190e+01
+2.007e+01
+1.825e+01
+1.642e+01
+1.460e+01
+1.277e+01
+1.095e+01
+9.124e+00
+7.299e+00
+5.474e+00
+3.650e+00
+1.825e+00
+0.000e+00

(a)

CNORMF, CNF3
+7.422e+01
+6.801e+01
+6.180e+01
+5.559e+01
+4.939e+01
+4.318e+01
+3.697e+01
+3.076e+01
+2.456e+01
+1.835e+01
+1.214e+01
+5.931e+00
-2.764e-01

(b)

Fig.5 Contact force distribution at the screw head
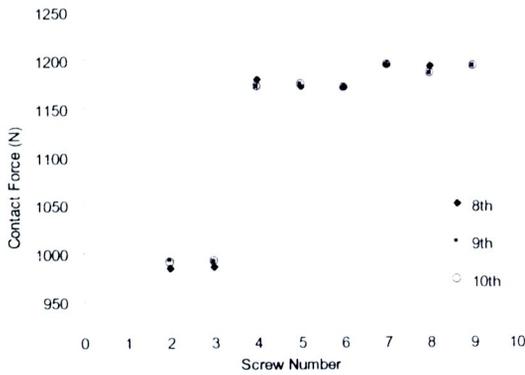
Fig. 6 Contact forces of screws in the 8th, 9th and 10th step

In addition, when the screws are re-fastened with the same torque in step 10, the change in the contact force is noticed to be limited to only the tightened screws as all other contact forces in step 9 and 10 are the same. Therefore, screw re-tightening process is suggested to be used after all screws are fastened to regain the loosened torque.

4. Conclusions

The screw tightening process to attach the top cover of a 3.5-inch HDD to its base is modeled and analyzed. Large deformations of the top cover are noticed along the edges, especially at the corners, where the contact force between the screw heads and the top cover take place only at the perimeters of the screw heads. Moreover, when a screw is tightened, torque loosening of other screws in a close proximity to the current screw is observed. The step of screw re-fastening can restore the screw tightness without any effect to other screws. Further study on the optimum tightening sequence and applied torques to improve the contact pressure distribution and minimize the looseness is recommended.

Acknowledgment

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Simulation," in *Abaqus Users' Conference*, Rhode Island, May. 2008, pp. 1-18.

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รูปที่ ข.2 ใบปิดหน้างานสัมมนาวิชาการ The 2nd International Conference on Mechanical, Industrial, and Manufacturing Technologies (MIMT 2011)

Effects of Screw Fastening Sequence to Top cover Loosening in Hard Disk Drive Assembly

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Abstract— In hard disk drive assembly process, a number of small screws around the perimeter of the top cover are used to attach the top cover to the base. When one of the screws is fastened, screw loosening at the other screw heads can frequently be observed. . This research employs a three-dimensional finite element analysis to compare the effects of three different screw tightening sequences to top cover loosening in a 3.5-inch hard disk drive assembly. The top cover deformation and the contact forces at the screw heads of the three sequences are presented and discussed. Among the three sequences, the across pattern has shown to be the most appropriate sequence in which a minimum screw loosening occurs.

Keywords- screw fastening sequence; hard disk drive assembly; torque loosening; finite element analysis

I. INTRODUCTION

In the process of hard disk assembly, the hard disk is mounted into an enclosure to seal it against dust and other contamination from the outside air. The drive mechanics are put into the base casting. A rubber gasket is put between the two parts to ensure a tight seal and a number of small screws are used to attach the top cover to the base. Most of the screws are located around the perimeter of the cover. Additional screws are also placed to secure the pivot position, the spindle motor shaft and the voice coil motor.

In the screw fastening process, a pre-torque is first applied to locate all screws in their positions. Subsequently, the required torque for each screw is consecutively applied to fasten the top cover and the base together. Screw loosening, in which the screw tightness is lower than the applied torque, is frequently observed after the tightening process. The screw loosening affects the seal tightness and the misalignment of the top cover and the base and causes problems in disk reading and recording. This work focuses on investigating the effects of different screw tightening sequences on the torque loosening and the top cover deformation of a 3.5-inch hard disk drive by using finite element analysis.

Izumi [1] analyzed the tightening and the loosening mechanism of threaded fastener. It was found that the fastener loosening due to shear loading is initiated when complete thread slip had occurred prior to head slip. Montgomery [2]

studied the influence of the boundary condition and the software setting in simulating 3D solid bolt to decrease run-times in finite element method. The smear contact at the thread region results in the same stress distribution as the thread contact modeling. The appropriate bolt simulation method is dependent on the time constraint, model size or local accuracy desired. Suknikhom [3] studied the effects of the screw tightening process to the stress distribution in the top cover. When a screw is tightened, change in contact pressure distributions at the other screw heads in proximity to the tightening screw was observed.

In the current study, the screw tightening sequence of a hard disk drive is examined by using a commercial finite element analysis program, ABAQUS [4]. Three different patterns of screw tightening sequence are investigated. Effects of changing the screw fastening sequences are discussed and the appropriate sequence is recommended.

II. FINITE ELEMENT MODELING AND ANALYSIS

The hard disk drive model used in the analysis is shown in Fig. 1. The model consists of the base casting, the top cover with a rubber gasket and the screws. The spindle motor, pivot and voice coil motor (VCM) are included in the base model.
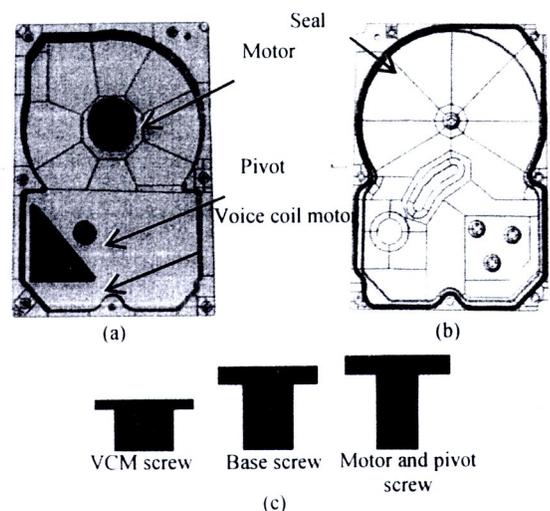

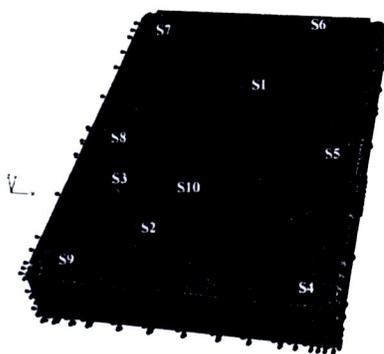Figure 1. Hard disk drive model (a) base (b) top cover (c) three types of screws.

Figure 2. Screw positions and boundary conditions for analysis

Ten screws of three different dimensions are used to attach the top cover to the base. The VCM screw has the shortest thread region with diameter of 3 mm. The base screw is 2.5 mm in diameter and the motor and pivot screw is 2 mm in diameter. The numbering and locations of the ten screws are shown in Fig. 2. The screws S1 and S10 are used to attach the top cover to the spindle motor and pivot, respectively. The screws S2 and S3, called VCM screw, are used to assemble the top cover to the voice coil motor. The other six screws, S4 to S9, are base screw. They are in the perimeter of the base and are used to tighten the top cover to the base.

In the screw fastening process, the hard disk assembly is put in an automatic screw driving machine where it is clamped on both sides. In the finite element model, the boundary conditions are applied as fixed condition at the bottom and on both sides of the base casting as shown in Fig. 2. The interaction between the screw head and the top cover is set as frictional contacts with the friction coefficient of 0.15. The contact surface between the base and the rubber gasket at the top cover is set as frictionless. The interactions in the thread region between the screw threads and the base are specified as tied contacts.

The material mechanical properties used in the analysis are listed in Table I. The hard disk drive base is made of aluminum alloy ADC12. The spindle motor, the pivot and top cover are stainless steel SUS 304. The screws are made of stainless steel SUS XM7.

The meshing of the FE model is shown in Fig. 3. The model is meshed by using three dimensional 8-node stress elements. The element shapes are mixed between hexahedral and tetrahedral elements.

To improve the quality of the mesh, the model is partitioned into several parts. Small element sizes are employed near the contact areas, especially, those between the screws and their contact partners.

III.   LOADING CONDITIONS AND ANALYSIS STEPS

Three proposed screw fastening sequences, namely *circular*, *across*, and *zigzag*, are modeled and studied. The sequences in the three models are shown by the numbering in Fig. 4. In all models, the first, the second and the third steps in the three sequences are the same, that is the motor and the two VCM screws are fastened. In the circular model, step 4 starts at screw S4 at the bottom right of the hard disk assembly. Then, the steps follow a circular pattern along the periphery of the base (Fig. 4a). The screws S5 to S9 are fastened, respectively. Steps 10 to 13 are the screw re-fastening with the same torque and a higher torque is applied to screw S1 in step 14.

The sequence trend line for the across model is shown in Fig. 3b. After step 3, the screw S4 is fastened. Then, the fastening process continues to the farthest screw, S7. The tightening steps 6 to 9 go on to the screws at the across positions to the previously tightened screws, i.e., to the screws S9, S6, S5 and S8, respectively. Again, after all screws are fastened, steps 10 to 12 are re-tightening of screws with the same torque and the same sequence as in the circular model. The screw S10 is tightened in step 13. Finally, the required torque is applied to the screw S1 in step 14.

The zigzag model follow a crisscross pattern as illustrated in Fig. 3c. Steps 1 to 3 are the same as the other two models. After that, the screw S6 is fastened in step 4. Next, the screw S7, S5, S8, S4 and S9 are tightened, respectively. Steps 10 to 14 are the same as the across model.
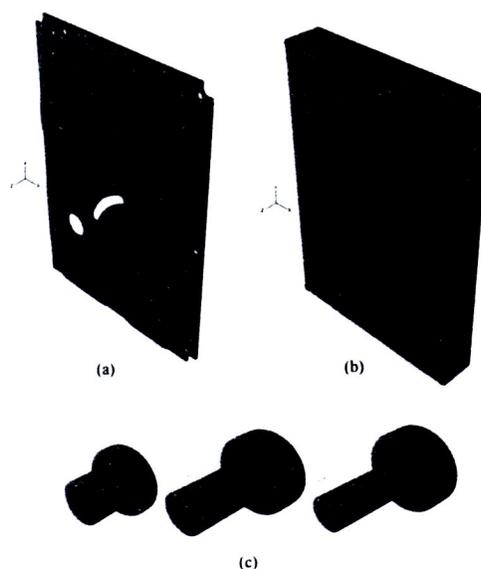

(a)   (b)

(c)

Figure 3. Meshing of FE model (a) top cover (b) base (c) screws.

TABLE I.   MECHANICAL PROPERTIES OF MATERIALS

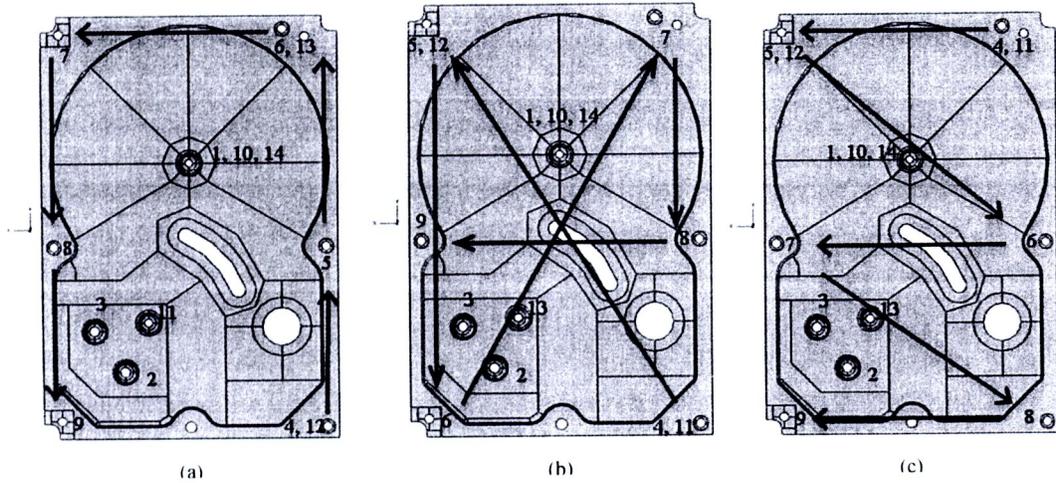| Properties	Material		
	ADC1 2	SUS 304	SUS XM7
Density (g/cm³)	2.70	8.00	8.00
Modulus of Elasticity (GPa)	69.16	193.00	193.00
Yield strength (MPa)	183.00	205.00	205.00
Poisson's ratio	0.33	0.30	0.30

Figure 4. The sequence trend lines for the three model (a) circular (b) across (c) zigzag.

To generate the tightening torque in the finite element analysis, the torque is computed as a bolt load applied to the internal surface between the head and the shank of the screw. The bolt load, P, is calculated from [5]

$$P = \frac{T}{Kd} \tag{1}$$

where T is the applied tightening torque, d is the screw diameter and K is the torque coefficient obtained as

$$K = \left(\frac{d_m}{2d}\right)\left(\frac{\tan\lambda + f\sec\alpha}{1 + f\tan\lambda\sec\alpha}\right) + 0.625 f_c \tag{2}$$

The parameter d_m is the average screw diameter, α is the thread angle, λ is the screw lead angle, f is friction coefficient of thread and f_c is the friction coefficient of bearing

Table II lists the torque coefficient K and the bolt loads for each screw computed from Eq. (2) and Eq. (1), respectively. For example, the screw S1 is 2 mm in diameter. From JIS standard [6], the average screw diameter d_m is 1.7835 mm. The screw parameter α is 30°, λ is 4.08, and f and f_c are 0.15. Therefore, the torque coefficient K is determined as 0.2015. When the tightening torque of 6 kgf.cm is applied to the screw, the bolt load P computed from (1) is 1460 N.

The bolt loads applied to the screws are the same for all three models. The motor screw S1 is fastened by the torque 8 kgf.cm whereas the screws S2 to S10 are tightened with the torque of 6 kgf.cm.

IV. RESULTS AND DISCUSSIONS

The deformed shapes of the top cover after all screw loads are applied are similar for all the three models. Small displacement is noticed in the

middle area of the hard disk assembly in which there exist the spindle motor, pivot and voice coil motor as the supports to the top cover. A larger displacement occurs along the edges of the top cover due to the displacement of the rubber gasket from the screw loads. Fig. 5 shows the displacement magnitude in the deformed configuration of the top cover. The displacements in the negative z-direction are much larger than those in the x- and y- directions. The maximum displacement is observed at the upper right corner of the top cover with displacement magnitude of 0.6246 mm.

TABLE II. BOLT LOADS APLLIED TO THE SCREW MODEL

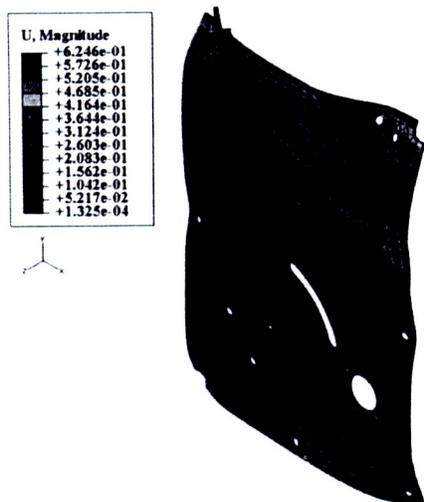| Screw number	Diameter (mm)	Torque coefficient (K)	Applied torque (kgf.cm)	Bolt load (N)
S1	2	0.2015	8	1947
S2, S3	3	0.1980	6	991
S4-S9	2.5	0.1974	6	1193
S10	2	0.2015	6	1460

Figure 5. The deformed shapes and displacements of top cover (magnified 15 times) for three models.
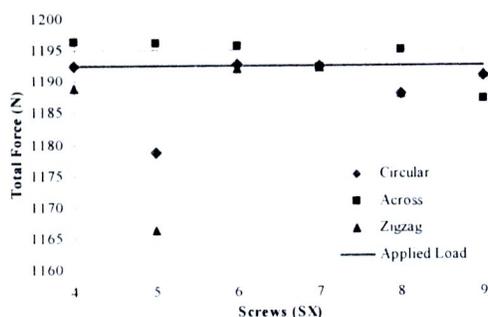

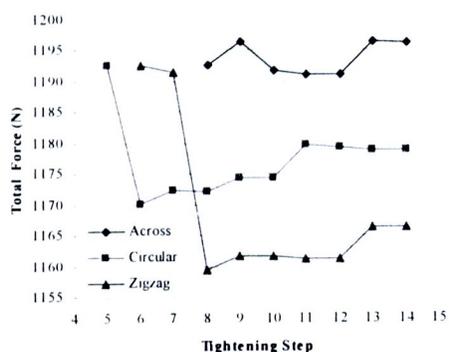Figure 6. The contact normal forces at the screws S4 to S9.

Figure 7. The total contact force at the head of the screw S5.

Loosening of screws is detected by the difference between the applied bolt load and the total contact normal forces at all nodes in the contact areas between the screw head and the top cover. Fig. 6 shows an example of the changes in the total force at the head of screw S5 for the three models. The applied bolt loads are the same and are equal to 1193 N. However, the screw S5 are not fastened at the same step in the three models. For the circular, across and zigzag models, the screw S5 is tightened in step 5, 8 and 6, respectively. Note that, the connected line for each model is plotted to emphasize the tendency of the force value after each tightening step. It does not

imply a linear change of the total force in-between the steps. It can be clearly seen from the figure that the total force at the head of screw S5 is affected by the fastening of other screws in the followed steps. Screw loosening is observed in the circular and the zigzag models while no loosening of screw S5 is perceived in the across model.

The contact normal forces at the screws S4 to S9 of the three models after the final steps are plotted in Fig. 6. The applied bolt load to the screws equal to 1193 N is depicted as a horizontal line in the graph. It can be seen from the figure that although the applied loads are the same for all three models, the final contact forces at all screws in the across model are the highest. In the circular and the zigzag models, loosening occurs at the screws S5, S8 and S9. The zigzag model results in the least torque at all screws and therefore is not recommended in the screw tightening process.

From the plot, the across model appears to be the best sequence among the proposed sequences since the total contact forces at all screws are consistent. In this model, loosening occurs only at the screw S9. This is because the crosswise screw tightening decreases bending in the top cover and each screw tightening step has less effect to the other screws.

V. CONCLUSIONS

The screw tightening process to assemble the top cover to the base for a 3.5-inch hard disk drive is modeled and analyzed. Three different screw tightening sequences with circular, across and zigzag patterns are examined. The tightening torque of the screw fastened in the previous step is shown to be affected by the screw tightened in the current step. This causes looseness of the top cover. Among the three suggested sequences, the across pattern has shown to be the most effective sequence in which a minimum screw loosening occurs.

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cover in the hard disk drive assembly" TSME-ICOME 2010, Ubon Ratchathani, October 2010.

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ประวัติผู้วิจัย

ชื่อ – สกุล	นายกำพล ศุขนิคม
วัน เดือน ปีเกิด	28 ตุลาคม 2528

ประวัติการศึกษา

ระดับมัธยมศึกษา	ประโยคมัธยมศึกษาตอนปลาย
	โรงเรียนภูเก็ตวิทยาลัย พ.ศ. 2546
ระดับปริญญาตรี	วิศวกรรมศาสตรบัณฑิต สาขาวิชาวิศวกรรมเครื่องกล
	มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี พ.ศ. 2550
ระดับปริญญาโท	วิศวกรรมศาสตรมหาบัณฑิต สาขาวิชาวิศวกรรมเครื่องกล
	มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี พ.ศ. 2554

ทุนการศึกษา ทุนสนับสนุนโครงการพัฒนาทรัพยากรบุคคล ในอุตสาหกรรม ฮาร์ดดิสก์ไดร์ฟ (HDD Cluster) สำหรับนักศึกษาระดับปริญญาตรี ปริญญาโทและปริญญาเอก โดยศูนย์วิจัยร่วมเฉพาะทางด้านการ ผลิตขั้นสูงในอุตสาหกรรมฮาร์ดดิสก์ไดร์ฟ และศูนย์เทคโนโลยี อิเล็กทรอนิกส์และคอมพิวเตอร์แห่งชาติ (NECTEC) ปีงบประมาณ 2551-2553 สัญญาทุนเลขที่ HDD-06-08-51M/2

ผลงานที่ได้รับการเผยแพร่ Suknikhom K., Kamnerdtong T. and Jongpradist P., "Study of Screw Tightening Sequence on the Looseness of the Top Cover in the Hard Disk Drive Assembly", **The First TSME International Conference on Mechanical Engineering**, 20-22 October, 2010, Ubon Ratchathani, Thailand

Suknikhom K., Jongpradist P., Chutima S. and Kamnerdtong T., "Effects of Screw Fastening Sequence to Top cover Loosening in Hard Disk Drive Assembly", **The 2nd International Conference on Mechanical, Industrial, and Manufacturing Technologies (MIMT 2011)**, 26-28 February, 2011, Singapore

มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี
ข้อตกลงว่าด้วยการโอนลิขสิทธิ์ในทรัพย์สินทางปัญญาของนักศึกษาระดับบัณฑิตศึกษา

วันที่ __4__ เดือน __ตุลาคม__ พ.ศ. __2554__

ข้าพเจ้า (นาย/~~นาง/นางสาว~~) __กำพล ศุขนิคม__ รหัสประจำตัว __51400134__ เป็นนักศึกษาของมหาวิทยาลัยเทคโนโลยี
พระจอมเกล้าธนบุรี ระดับ ☐ ประกาศนียบัตรบัณฑิต ☑ ปริญญาโท ☐ ระดับปริญญาเอก หลักสูตร __วิศวกรรมศาสตรมหาบัณฑิต__
สาขาวิชา __วิศวกรรมเครื่องกล__ คณะ __วิศวกรรมศาสตร์__ อยู่บ้านเลขที่ __249/8__ หมู่ __-__ ตรอก/ซอย __แสนสุข1__ ถนน __ภูเก็ต__ ตำบล/
แขวง __ตลาดใหญ่__ อำเภอ/เขต __เมือง__ จังหวัด __ภูเก็ต__ รหัสไปรษณีย์ __83000__ เป็น "ผู้โอน" ขอโอนลิขสิทธิ์ในทรัพย์สินทางปัญญาให้ไว้
กับมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี โดยมี (ชื่อคณบดี)) __รศ.ดร.ปิยะบุตร วานิชพงษ์พันธุ์__ ตำแหน่ง รองคณบดีฝ่ายวิชาการ
ปฏิบัติการแทนคณบดีคณะวิศวกรรมศาสตร์ เป็นตัวแทน "ผู้รับโอน" สิทธิในทรัพย์สินทางปัญญาและมีข้อตกลงดังนี้

1. ข้าพเจ้าได้จัดทำวิทยานิพนธ์เรื่อง __การวิเคราะห์กระบวนการขึ้นแน่นฝาปิด ของฮาร์ดดิสก์ไดรฟ์ขนาด 3.5 นิ้ว โดย
วิธีไฟไนต์เอลิเมนต์__ ซึ่งอยู่ในความควบคุมของ __ผศ.ดร.ภัทรมน จงประดิษฐ์__ ตามพระราชบัญญัติลิขสิทธิ์ พ.ศ. 2537
และถือว่าเป็นส่วนหนึ่งของการศึกษาตามหลักสูตรของมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี

2. ข้าพเจ้าตกลงโอนลิขสิทธิ์จากผลงานทั้งหมดที่เกิดขึ้นจากการสร้างสรรค์ของข้าพเจ้าในวิทยานิพนธ์ให้กับมหาวิทยาลัย
เทคโนโลยีพระจอมเกล้าธนบุรี ตลอดอายุแห่งการคุ้มครองลิขสิทธิ์ตามพระราชบัญญัติลิขสิทธิ์ พ.ศ. 2537 ตั้งแต่วันที่
ได้รับอนุมัติโครงร่างวิทยานิพนธ์จากมหาวิทยาลัย

3. ในกรณีที่ข้าพเจ้าประสงค์จะนำวิทยานิพนธ์ไปในการเผยแพร่ในสื่อใด ๆ ก็ตาม ข้าพเจ้าจะต้องระบุว่าวิทยานิพนธ์เป็น
ผลงานของมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรีทุกครั้งที่มีการเผยแพร่

4. ในกรณีที่ข้าพเจ้าประสงค์จะนำวิทยานิพนธ์ไปเผยแพร่ หรือให้ผู้อื่นทำซ้ำหรือดัดแปลงหรือเผยแพร่ต่อสาธารณชนหรือ
กระทำการอื่นใด ตามพระราชบัญญัติลิขสิทธิ์ พ.ศ. 2537 โดยมีค่าตอบแทนในเชิงธุรกิจ ข้าพเจ้าจะกระทำได้เมื่อได้รับ
ความยินยอมเป็นลายลักษณ์อักษรจากมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรีก่อน

5. ในกรณีที่ข้าพเจ้าประสงค์จะนำข้อมูลจากวิทยานิพนธ์ไปประดิษฐ์หรือพัฒนาต่อยอดเป็นสิ่งประดิษฐ์หรืองานทรัพย์สินทาง
ปัญญาประเภทอื่น ภายในระยะเวลาสิบ (10) ปีนับจากวันลงนามในข้อตกลงฉบับนี้ ข้าพเจ้าจะกระทำได้เมื่อได้รับความ
ยินยอมเป็นลายลักษณ์อักษรจากมหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี และมหาวิทยาลัยเทคโนโลยีพระจอมเกล้า
ธนบุรีมีสิทธิในทรัพย์สินทางปัญญานั้น พร้อมกับได้รับชำระค่าตอบแทนการอนุญาตให้ใช้สิทธิดังกล่าว รวมถึงการจัดสรร
ผลประโยชน์อันพึงเกิดขึ้นจากส่วนใดส่วนหนึ่งหรือทั้งหมดของวิทยานิพนธ์ในอนาคต โดยให้เป็นไปตามระเบียบสถาบัน
เทคโนโลยีพระจอมเกล้าธนบุรี ว่าด้วย การบริหารผลประโยชน์อันเกิดจากทรัพย์สินทางปัญญา พ.ศ. 2538

6. ในกรณีที่มีผลประโยชน์เกิดขึ้นจากวิทยานิพนธ์หรืองานทรัพย์สินทางปัญญาอื่นที่ข้าพเจ้าทำขึ้นโดยมีมหาวิทยาลัย
เทคโนโลยีพระจอมเกล้าธนบุรีเป็นเจ้าของ ข้าพเจ้าจะมีสิทธิได้รับการจัดสรรผลประโยชน์อันเกิดจากทรัพย์สินทางปัญญา
ดังกล่าวตามอัตราที่กำหนดไว้ในระเบียบสถาบันเทคโนโลยีพระจอมเกล้าธนบุรี ว่าด้วย การบริหารผลประโยชน์อันเกิด
จากทรัพย์สินทางปัญญา พ.ศ. 2538

ลงชื่อ __กำพล ศุขนิคม__ ผู้โอนลิขสิทธิ์
(นายกำพล ศุขนิคม)

ลงชื่อ _____ ผู้รับโอนลิขสิทธิ์
(รศ.ดร.ปิยะบุตร วานิชพงษ์พันธุ์)
รองคณบดีฝ่ายวิชาการ ปฏิบัติการแทนคณบดี

ลงชื่อ _____ พยาน
(ผศ.ดร.ภัทรมน จงประดิษฐ์)

ลงชื่อ _____ พยาน
(รศ.ดร.พงศ์พันธ์ แก้วตาทิพย์)