Analysis and Optimization of the Tensioning Effect on a Wood-Cutting Circular Saw Blade Tensioned by Multispot Pressure

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Abstract

In recent years, a multispot pressure tensioning process appeared in the field of circular saw blade manufacturing. Due to the insufficient understanding about the formation and evolution of the tensioning effect of this process, this study aimed to analyze and optimize the tensioning effect on a circular saw blade tensioned by multispot pressure. It could provide a theoretical basis and key technical parameters for regulating and controlling the tensioning effect of this process. In this article, the natural frequency and the tensioning stress field of a circular saw blade tensioned by multispot pressure were calculated by ABAQUS software. The simulated tensioning stress field was in agreement with the experimental results, which confirmed the accuracy of the simulation model. The influence of process parameters on the natural frequency and tangential tensile stress in the edge of the circular saw blade was examined and compared based on the orthogonal method. Simulation results show that the parameters of the multispot pressure tensioning process have different degrees of influence on the tensioning effect of a circular saw blade. Considering the natural frequency and tangential tensile stress in the edge of a circular saw blade synthetically, optimal process parameters for multispot pressure tensioning were obtained.

Presently, there is a shortage of wood resources in the world, especially in China. Wood processing enterprises all over the world have placed greater demands on the cutting precision and material-saving ability of circular saw blades. Presently, circular saw blades are becoming thinner and thinner in order to reduce kerf loss.

Wood cutting requires a circular saw blade to maintain optimal working condition for a long period of time. Thermal stress is produced, because the temperature at the edge of the blade is higher than that in other regions. High tangential compressive stress is produced in the edge of a circular saw blade because of thermal stress, causing a buckling deformation that reduces cutting precision, increases kerf loss, and shortens the saw's life. The above-mentioned phenomenon can easily occur in the case of a thin circular saw blade. In the field of wood sawing, a circular saw blade is expected to be thinner and better because of the shortage of wood resources and enhancement of environmental protection. Therefore, improved stability performance of wood-cutting circular saw blades is very important.

During the manufacturing of circular saw blades, tensioning is the most important and advanced technological process in order to avoid the phenomenon mentioned above. The natural frequency and the residual stress field of a circular saw blade are changed after the tensioning process, which is called the tensioning effect. The tensioning effect has a strong influence on cutting quality, noise, vibration, material waste, and lifetime of a circular saw blade (Li et al. 2016).

In recent years, a multispot pressure tensioning process appeared in the field of circular saw blade manufacturing. Based on a hydraulic control system, many local areas of a circular saw blade are pressed by a spherical surface, and plastic deformation is produced during this process. The feasibility and effectiveness of this process were confirmed based on a theoretical analysis and tensioning stress test (Li et al. 2015a). The multispot pressure tensioning process is effective for any circular saw blade, especially a wood-

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cutting circular saw blade, because the phenomenon of cutting heat is more obvious on a wood-cutting circular saw blade.

Roll tensioning and hammering were the main tensioning methods for circular saw blades before the emergence of the multispot pressure tensioning process. Many scientists have studied the tensioning effect of circular saw blades tensioned by these two methods, as discussed below.

The dynamic characteristics of a roll-tensioned circular saw blade with a tensioning stress field were determined by Carlin et al. (1975) based on energy methods. The light gap between the blade surface and edge of a curved ruler was tested by Schajer (1992) for characterizing tensioning effect indirectly. Lateral stiffness of a circular saw blade in coordination of tensioning effect with rotation speed was studied by Stakhiev (2004). A modal filter was used by Kuratani and Oda (2010) for measuring the natural frequency of a roll-tensioned saw blade. An experimental platform was built by Schajer et al. (2012) for examining the vibration mode and controlling tensioning effect. An analysis model for the dynamic characteristics of a circular saw blade under a thermal load was built (Ishihara et al. 2012, 2014). Effects of roll-tensioning process parameters on the natural frequency of a circular saw blade were studied by Cristóvão et al. (2012) based on ABAQUS software. The influence of the tangential roll-tensioning process on the natural frequency of a circular saw blade was studied by Zhang et al. (2014). An active electromagnetic system for weakening the vibrations of a circular saw blade was proposed by Gospodaric et al. (2015).

The tensioning stress field of a roll-tensioned circular saw blade was tested by Szymani and Mote (1974). The tensioning stress field of a roll-tensioned circular saw blade was obtained by Szymani and Mote (1979) based on experimental measurement and theoretical analysis. A theoretical model was presented by Schajer and Mote (1983) that could accurately describe the tensioning stress field in a roll-tensioned circular saw blade. A mathematical model that could predict the optimal roll-tensioning parameters for a saw blade was built by Schajer and Mote (1984). The X-ray stress test method for measuring the tensioning stress field of a roll-tensioned circular saw blade was studied by Umetsu et al. (1989). Umetsu et al. (1994) measured the tensioning stress field in a hammering-tensioned circular saw blade using the X-ray stress meter. Nicoletti et al. (1996) built a finite element model for the roll-tensioning process and examined the tensioning stress field. The effects of roll-tensioning parameters on the tensioning stress field were examined by Heisel et al. (2014) through ABAQUS software. The effect of yield strength on the tensioning stress field of a roll-tensioned circular saw blade was studied by Li and Zhang (2017) through ABAQUS software.

The multispot pressure tensioning process has its own advantages of automatic control and tensioning effect optimization (Li et al. 2015b, 2015c). However, there is no related research on the regulation mechanism of the tensioning effect and optimized process parameters for this process. The lack of theoretical basis restricts the development of a multispot pressure tensioning process.

The natural frequency and tensioning stress field of a circular saw blade are two of the most important indicators for the tensioning effect. The optimal tensioning effect and process parameters for multispot pressure tensioning could be obtained only by considering these two indicators synthetically. Therefore, analysis and optimization of the tensioning effect for a circular saw blade tensioned by multispot pressure were carried out in this article.

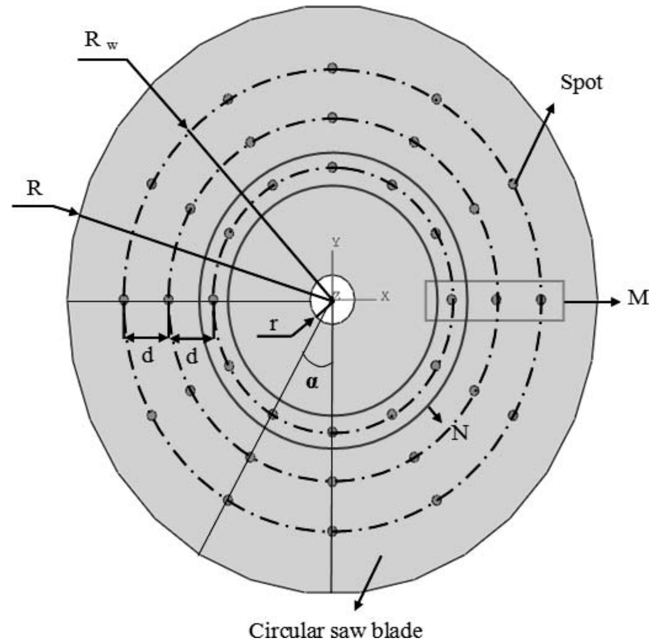

Figure 1.—Representative process parameters for multispot pressure tensioning process. F = loading force; M = radial spot number; N = circumferential spot number; R = radius; R_w = radius of spots in the outermost ring; d = radial distance.

Materials and Methods

Process parameters for a multispot pressure tensioning process

According to the characteristics of a multispot pressure tensioning process, representative process parameters are summarized in this article. The representative process parameters for a multispot pressure tensioning process include the following: loading force (F), radial spot number (M), circumferential spot number (N), radius of spots in the outermost ring (R_w), and radial distance (d), as shown in Figure 1. These process parameters have effects on the natural frequency and tensioning stress field of a circular saw blade. The spot distribution is cyclic axisymmetric. In Figure 1, $\alpha = \frac{360}{N}(°)$.

The circular saw blade chosen in this study is from a sliding table saw. It needs to maintain durable and stable cutting performance and cutting accuracy. The radius and thickness of the circular saw blade were 178 and 2.2 mm, respectively, which were unchanged. The radius of the hole in the center of the circular saw blade was 15 mm and unchanged. The number of teeth was 36 with carbide tips. There was no expansion slot. F was changed from 40 to 80 kN, M was changed from 2 to 4, N was changed from 12 to 16, R_w was changed from 130 to 150 mm, and d was changed from 20 to 30 mm in the research process described in this article. Factors and their levels for the orthogonal simulation experiment in this article are shown in Table 1.

Table 1.—Factors and their level of multispot pressure tensioning process.

Level	Factor[a]				
	F (kN)	M	N	R_w (mm)	d (mm)
1	40	2	12	150	30
2	60	3	14	140	25
3	80	4	16	130	20

[a] F = loading force; M = radial spot number; N = circumferential spot number; R_w = radius of spots in the outermost ring; d = radial distance.

Tensioning effect analysis of circular saw blade based on finite element method

The Dynamic/Explicit module of ABAQUS software was chosen to simulate the elastic-plastic loading process of multispot pressure tensioning. One simulation for verification of the finite element model is shown in Figure 2, where F was set to 40 kN, M was set to 3, N was set to 16, R_w was set to 140 mm, and d was set to 30 mm.

Radius and thickness of the circular saw blade were 178 and 2.2 mm, respectively, which were unchanged. The radius of the hole in the center of circular saw blade was 15 mm and unchanged. Radius of spherical pressure head was 70 mm and unchanged.

The hardness of spherical pressure head was HRC60. Elastic deformation of the spherical pressure head was ignored, and it was built as an analytical rigid body. The main part of the circular saw blade was made of 65Mn, with hardness HRC42. The constitutive model of this material was set as a linear strengthening elastic-plastic model. Its elastic modulus, poisson ratio, and density were set as 210 GPa, 0.3, and 7.8 g/cm^3, respectively. Its yield strength and strain hardening rate were set as 430 and 1,000 MPa, respectively.

All the translational degrees of freedom at the inner wall of the center hole of the circular saw blade were restricted. Loading force was applied to the spherical head. Two planes of the circular saw blade were pressed by spherical pressure heads simultaneously. Kinetic friction was applied between the spherical pressure head and the circular saw blade; the friction coefficient was set to 0.12.

The spherical pressure head was not meshed. The three-dimensional eight-node reduced integral element C3D8R was chosen for the circular saw blade. There were 80 elements in radial direction, 384 elements in circumferential direction, and 2 elements in thickness direction of saw blade.

The tensioning stress field of the circular saw blade was calculated by the Static/General module of ABAQUS software using the stress field of loading process calculated by the Dynamic/Explicit module as initial conditions.

Natural frequencies of the circular saw blade were calculated by the Frequency module of ABAQUS software using the tensioning stress field calculated by the Static/General module as initial conditions.

Verification for the finite element model

The tensioning stress field is the most important link for the model, which can also determine the precision of the natural frequency. Therefore, the tensioning stress test was carried out to confirm the accuracy of the model. The tensioning stress field of the circular saw blade tensioned by multispot pressure was tested by the X-ray stress meter.

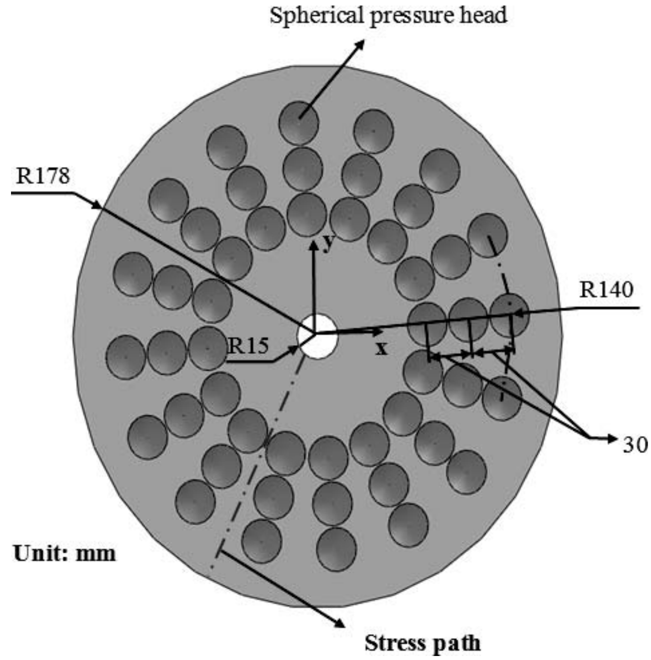

Figure 2.—Finite element model for multispot pressure tensioning process.

The spot distribution is shown in Figure 2, and F was set as 40 kN. The tensioning stress test path and numerical extraction path for tensioning stress calculation results were the same, as shown by the center line in Figure 2. The simulation results and stress measurement results are shown in Figure 3. The simulated tensioning stress field was in agreement with the measurement results, which confirmed the accuracy of the model.

Results and Discussion

For the circular saw blade after the tensioning process, natural frequencies for the nodal circle (Nc) = 0 and nodal diameter (Nd) < 2 generally are decreased slightly. Natural frequencies for Nc = 0 and Nd ≥ 2 are increased to different extents. The critical speed of the circular saw blade is primarily affected by the natural frequencies for Nc = 0 and Nd ≥ 2. In general, the increase of natural frequencies for Nc = 0 and Nd ≥ 2 is beneficial for a circular saw blade under the premise that the natural frequencies for Nc = 0 and Nd < 2 are unchanged or decreased slightly.

Tangential tensile stress is produced in the edge of a circular saw blade after the tensioning process. Tangential tensile stress in the edge of circular saw blade can compensate the tangential compressive thermal stress and improve the stability of circular saw blade under working conditions. In general, the increase of tangential tensile stress in the edge of a circular saw blade is beneficial for the circular saw blade under the premise that the natural frequencies of the circular saw blade are reasonable.

To summarize, the natural frequency and tangential tensile stress in the edge of a circular saw blade are two important indicators for tensioning effect, and are also the basis for the optimization of a multispot pressure tensioning process.

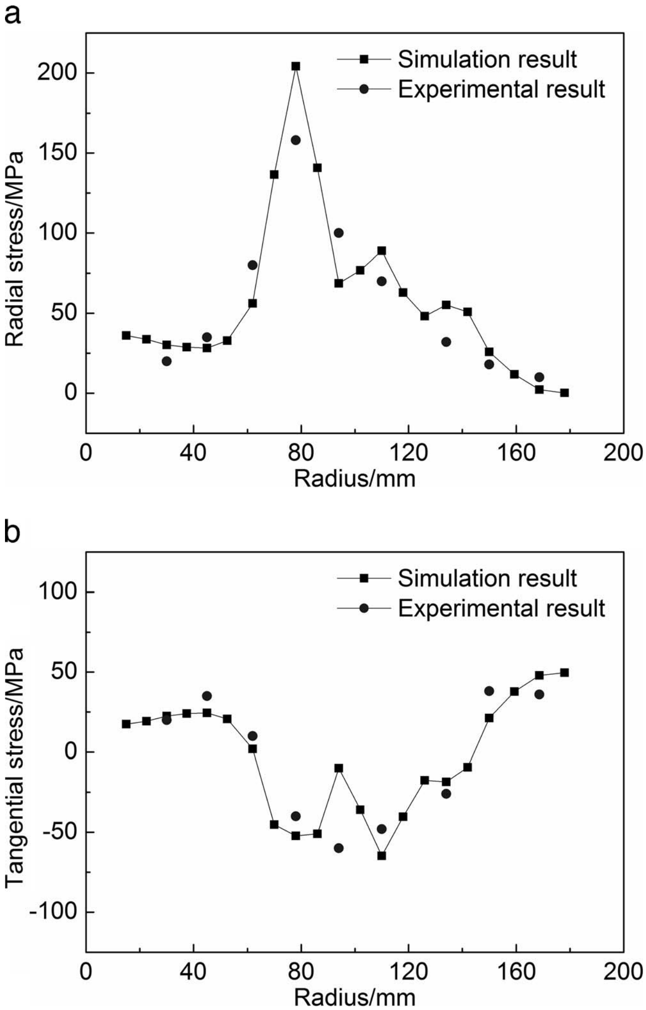

Figure 3.—Contrast of tensioning stress between simulation and experimental results. (a) Radial stress distribution. (b) Tangential stress distribution.

The natural frequency of the circular saw blade in its initial state is shown in Table 2. The natural frequency for Nc = 0 and Nd = 0 is slightly larger than that for Nc = 0 and Nd = 1. The natural frequency is increased with nodal diameter for Nc = 0 and Nd $\geq$ 1. The simulation results of the natural frequency of the circular saw blade were consistent with previous research results of other scientists (Szymani and Mote 1979, Schajer and Mote 1983), which also confirmed the accuracy of the finite element model in this study.

F, M, N, R_w, and d influence the tensioning effect. These factors also affect each other. When the influence of one factor on the tensioning effect is studied while the other factors are fixed, the degree of influence of different factors on the tensioning effect cannot be compared comprehensively. Therefore, the orthogonal experimental method was chosen for the optimization of a multispot pressure tensioning process. Because the orthogonal table has the characteristics of balanced dispersion, each test has a strong representation, thus ensuring the requirements of a comprehensive experiment.

The orthogonal table $L_{27}(3^{13})$ was used for the design of the orthogonal simulation experiment, as shown in Table 3. The natural frequency of tensioned the circular saw blade is shown in Table 4. Average tangential tensile stress in the edge of the circular saw blade is also shown in Table 4. According to the principle of the orthogonal experiment, all of the following analyses were based on Tables 3 and 4. For example, if the effect of F on the natural frequency of Nc = 0 and Nd = 0 needs to be studied, the natural frequencies of Nc = 0 and Nd = 0 when F = 40, 60, or 80 kN from Table 4 are averaged separately. In the same way, the natural frequencies of Nc = 0, Nd > 0, and average tangential tensile stress in the edge of the circular saw blade when F = 40, 60, or 80 kN are extracted from Table 4 and averaged separately. Tables 5 through 9 were obtained by this method, which allows us to compare the degree of influence of these factors on tensioning effect comprehensively and find the optimized scheme for a multispot pressure tensioning process.

As shown in Table 5, the effect of F on the natural frequencies of Nc = 0 and Nd $\geq$ 2 is limited. The average tangential tensile stress in the edge of the circular saw blade

Table 2.—Natural frequency of circular saw blade in initial state.

Modal[a]	Natural frequency (Hz)
Nc = 0, Nd = 0	69.40
Nc = 0, Nd = 1	55.45
Nc = 0, Nd = 2	94.86
Nc = 0, Nd = 3	213.18
Nc = 0, Nd = 4	373.88

[a] Nc = nodal circle; Nd = nodal diameter.

Table 3.—Design of orthogonal simulation experiment.

	Factor[a]				
Number	F (kN)	M	N	R_w (mm)	d (mm)
1	40	2	12	150	30
2	40	2	12	150	25
3	40	2	12	150	20
4	40	3	14	140	30
5	40	3	14	140	25
6	40	3	14	140	20
7	40	4	16	130	30
8	40	4	16	130	25
9	40	4	16	130	20
10	60	2	14	130	30
11	60	2	14	130	25
12	60	2	14	130	20
13	60	3	16	150	30
14	60	3	16	150	25
15	60	3	16	150	20
16	60	4	12	140	30
17	60	4	12	140	25
18	60	4	12	140	20
19	80	2	16	140	30
20	80	2	16	140	25
21	80	2	16	140	20
22	80	3	12	130	30
23	80	3	12	130	25
24	80	3	12	130	20
25	80	4	14	150	30
26	80	4	14	150	25
27	80	4	14	150	20

[a] F = loading force; M = radial spot number; N = circumferential spot number; R_w = radius of spots in the outermost ring; d = radial distance.

Table 4.—Results of orthogonal simulation experiment.

Number	Natural frequency (Hz)[a] Nc = 0 Nd = 0	Nc = 0 Nd = 1	Nc = 0 Nd = 2	Nc = 0 Nd = 3	Nc = 0 Nd = 4	Average tangential tensile stress in the edge of circular saw blade (MPa)
1	85.16	58.96	64.34	185.74	352.81	42.52
2	88.05	59.39	52.21	173.43	340.01	44.53
3	93.47	60.45	31.20	150.13	317.23	46.71
4	68.94	57.79	103.68	239.44	416.91	49.45
5	79.48	59.91	84.15	219.37	399.67	55.43
6	93.28	62.72	31.97	177.58	363.15	56.12
7	6.47	45.43	157.26	304.70	486.12	68.43
8	12.93	51.59	142.68	290.48	474.83	68.69
9	51.64	58.21	111.52	261.05	455.08	72.54
10	71.90	58.43	97.32	233.97	415.36	49.73
11	79.10	59.75	82.22	217.64	400.42	51.56
12	81.09	60.04	77.08	211.33	393.80	53.32
13	85.41	60.56	70.85	203.71	381.72	93.52
14	96.35	62.53	61.23	150.23	326.23	95.36
15	108.41	64.89	50.45	89.82	288.45	100.51
16	39.02	53.73	132.75	277.65	461.19	83.64
17	65.82	60.09	98.26	245.04	436.92	86.53
18	83.67	64.05	35.89	193.92	395.74	92.57
19	84.92	60.45	69.19	202.31	383.13	75.62
20	86.92	60.79	61.88	194.76	375.78	81.05
21	85.62	60.12	66.73	195.81	374.89	73.36
22	45.46	56.83	120.45	269.88	461.66	76.74
23	59.47	59.99	94.82	243.59	442.29	79.93
24	66.54	60.45	86.82	232.12	429.16	79.83
25	70.25	58.60	101.39	239.90	422.34	129.45
26	91.79	64.17	30.50	186.34	379.21	137.52
27	105.06	65.30	10.12	142.94	339.40	140.42

[a] Nc = nodal circle; Nd = nodal diameter.

is increased with F. As shown in Figure 4, the natural frequency of Nc = 0 and Nd = 2 is less than that of the circular saw blade in its initial state. The natural frequency of Nc = 0 and Nd = 4 is greater than that of the circular saw blade in its initial state.

As shown in Table 6, the effect of M on the dynamic characteristics of the circular saw blade is significant. The natural frequencies of Nc = 0 and Nd $<$ 2 have a certain degree of reduction with M. The natural frequencies of Nc = 0 and Nd $\geq$ 2 are increased significantly with M. The number of local plastic deformation regions is increased with M. The average tangential tensile stress in the edge of the circular saw blade is increased with M because of the superposition of tangential residual tensile stress. As shown in Figure 5, the natural frequencies of Nc = 0 and Nd $\leq$ 2 gradually align with those of the circular saw blade in its initial state with the increase of M. The natural frequencies of Nc = 0 and Nd $>$ 2 gradually exceed those of the circular saw blade in its initial state with the increase of M.

As shown in Table 7, the effect of N on the natural frequencies is limited. The average tangential tensile stress in the edge of the circular saw blade is increased with N within a limited range. As shown in Figure 6, the natural frequencies of Nd = 0, Nd = 1, and Nd = 3 with Nc = 0 is not changed significantly, compared with those of the circular saw blade in its initial state. The natural frequency of Nc = 0, Nd = 2 is less than that of the circular saw blade in its initial state. The natural frequency of Nc = 0, Nd = 4 is greater than that of the circular saw blade in its initial state.

As shown in Table 8, the effect of R_w on the dynamic characteristics of circular saw blade is significant. The natural frequencies of Nc = 0 and Nd $<$ 2 have a certain

Table 5.—Tensioning effect under different loading forces.

F (kN)[a]	Natural frequency (Hz) Nc = 0 Nd = 0	Nc = 0 Nd = 1	Nc = 0 Nd = 2	Nc = 0 Nd = 3	Nc = 0 Nd = 4	Average tangential tensile stress in the edge of circular saw blade (MPa)
40	64.38	57.16	86.55	222.43	400.64	56.04
60	78.97	60.45	78.45	202.59	388.87	78.52
80	77.33	60.74	71.32	211.96	400.87	97.10
Range	14.59	3.58	15.23	19.84	12.00	41.06

[a] F = loading force; Nc = nodal circle; Nd = nodal diameter.

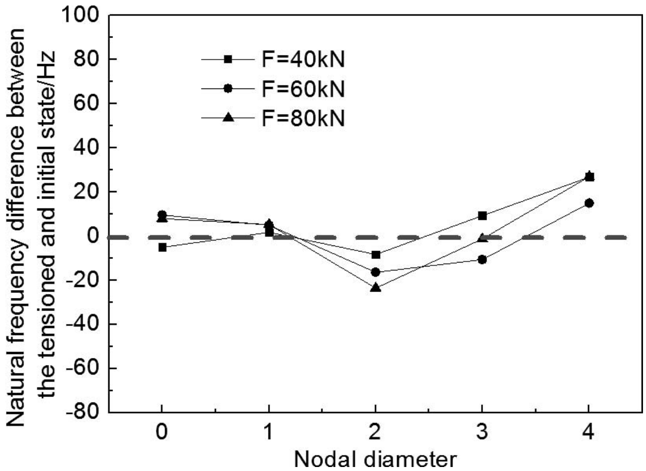

Figure 4.—Natural frequency difference between the tensioned and initial state under different loading forces (nodal circle = 0). F = loading force.

degree of reduction with the decrease of R_w. The natural frequencies of $Nc = 0$ and $Nd \geq 2$ are increased significantly with the decrease of R_w. The local plastic deformation regions extend to the center of the circular saw blade with the decrease of R_w. The average tangential tensile stress in the edge of the circular saw blade is decreased with the decrease of R_w in an acceptable degree. As shown in Figure 7, the natural frequencies of $Nc = 0$ and $Nd \leq 2$ gradually align with those of the circular saw blade in its initial state with the decrease of R_w. The natural frequencies of $Nc = 0$ and $Nd > 2$ gradually exceed those of the circular saw blade in its initial state with the decrease of R_w.

As shown in Table 9, the effect of d on the dynamic characteristics of circular saw blade is significant. The natural frequencies of $Nc = 0$ and $Nd < 2$ have a certain degree of reduction with d. The natural frequencies of $Nc = 0$ and $Nd \geq 2$ are increased significantly with d. The local plastic deformation regions extend to the center of the circular saw blade with d. The average tangential tensile stress in the edge of the circular saw blade is decreased with d to an acceptable degree. As shown in Figure 8, the natural

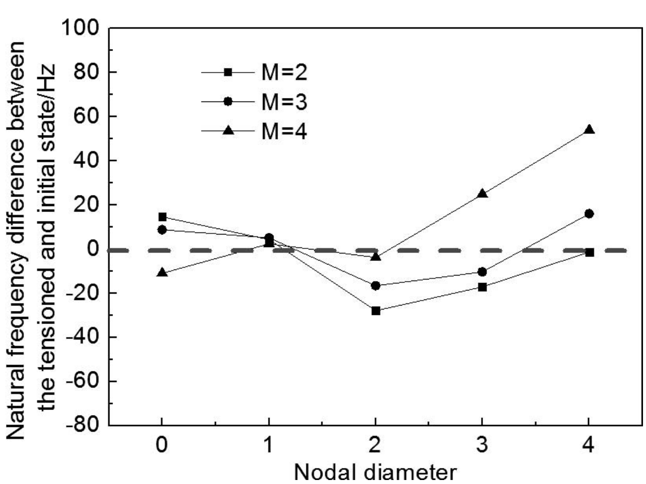

Figure 5.—Natural frequency difference between the tensioned and initial state under different radial spot numbers (nodal circle = 0). M = radial spot number.

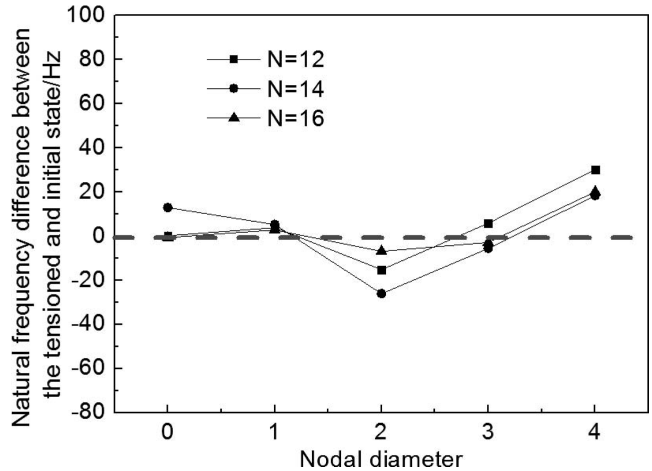

Figure 6.—Natural frequency difference between the tensioned and initial state under different circumferential spot number (nodal circle = 0). N = circumferential spot number.

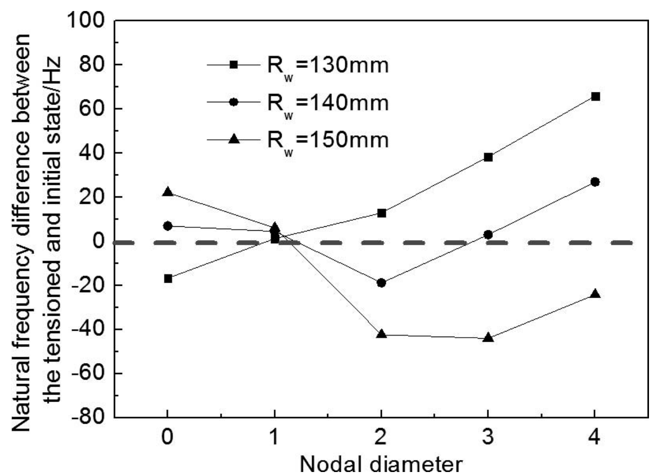

Figure 7.—Natural frequency difference between the tensioned and initial state under different radii of spots in the outermost ring (nodal circle = 0). R_w = radius of spots in the outermost ring.

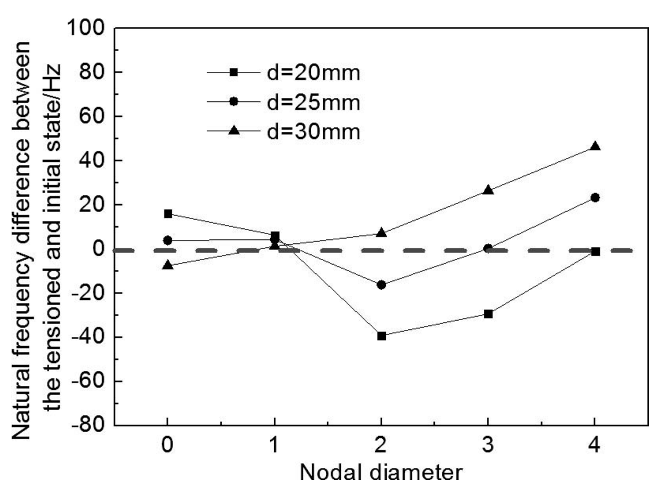

Figure 8.—Natural frequency difference between the tensioned and initial state under different radial distances (nodal circle = 0). d = radial distance.

Table 6.—Tensioning effect under different radial spot numbers.

	Natural frequency (Hz)					Average tangential tensile stress in the edge of circular saw blade (MPa)
M[a]	Nc = 0 Nd = 0	Nc = 0 Nd = 1	Nc = 0 Nd = 2	Nc = 0 Nd = 3	Nc = 0 Nd = 4	
2	84.02	59.82	66.90	196.12	372.60	57.60
3	78.14	60.63	78.26	202.86	389.91	76.32
4	58.51	57.90	91.15	238.00	427.87	97.75
Range	25.51	2.73	24.25	41.88	55.27	40.15

[a] M = radial spot number; Nc = nodal circle; Nd = nodal diameter.

Table 7.—Tensioning effect under different circumferential spot numbers.

	Natural frequency (Hz)					Average tangential tensile stress in the edge of circular saw blade (MPa)
N[a]	Nc = 0 Nd = 0	Nc = 0 Nd = 1	Nc = 0 Nd = 2	Nc = 0 Nd = 3	Nc = 0 Nd = 4	
12	69.62	59.32	79.63	219.05	404.11	70.33
14	82.32	60.74	68.71	207.61	392.25	80.33
16	68.74	58.28	87.97	210.31	394.02	81.00
Range	13.58	2.46	19.26	11.44	11.86	10.67

[a] N = circumferential spot number; Nc = nodal circle; Nd = nodal diameter.

Table 8.—Tensioning effect under different radii of spots in the outermost ring.

	Natural frequency (Hz)					Average tangential tensile stress in the edge of circular saw blade (MPa)
R_w (mm)[a]	Nc = 0 Nd = 0	Nc = 0 Nd = 1	Nc = 0 Nd = 2	Nc = 0 Nd = 3	Nc = 0 Nd = 4	
150	91.55	61.65	52.47	169.13	349.71	92.28
140	76.40	59.96	76.05	216.20	400.82	72.64
130	52.73	56.74	107.79	251.64	439.85	66.75
Range	38.82	4.91	55.32	82.51	90.14	25.53

[a] R_w = radius of spots in the outermost ring; Nc = nodal circle; Nd = nodal diameter.

Table 9.—Tensioning effect under different radial distances.

	Natural frequency (Hz)					Average tangential tensile stress in the edge of circular saw blade (MPa)
d (mm)[a]	Nc = 0 Nd = 0	Nc = 0 Nd = 1	Nc = 0 Nd = 2	Nc = 0 Nd = 3	Nc = 0 Nd = 4	
30	61.94	56.75	101.91	239.70	420.13	74.34
25	73.32	59.80	78.66	213.43	397.26	77.84
20	85.42	61.80	55.75	183.85	372.98	79.48
Range	23.48	5.05	46.16	55.85	47.15	5.14

[a] d = radial distance; Nc = nodal circle; Nd = nodal diameter.

frequencies of Nc = 0 and Nd $\leq$ 2 gradually align with those of the circular saw blade in its initial state with d. The natural frequencies of Nc = 0 and Nd $>$ 2 gradually exceed those of the circular saw blade in its initial state with d.

The degree of influence of process parameters on the natural frequencies of the circular saw blade, as characterized by Δf, is shown below:

$$\Delta f = \left(\sum_{i-0,j-0}^{j-4} \Delta f_{ij} \right) / 5 \quad (1)$$

where Δf_{ij} represents the range of the natural frequency, i represents Nc, and j represents Nd.

According to the data in Tables 5 through 9, Δf values were calculated as shown below. For F, $\Delta f = 13.05$ Hz; for M, $\Delta f = 29.93$ Hz; for N, $\Delta f = 11.72$ Hz; for R_w, $\Delta f = 54.34$ Hz; and for d, $\Delta f = 35.54$ Hz.

According to Δf and Figures 4 through 8, R_w has the greatest effect on the natural frequencies of the circular saw blade. The tensioning effect is enhanced with the decrease of R_w. Dynamic characteristics can be regulated and controlled effectively by adjusting R_w within the appropriate range.

M and d have the second greatest effects on the natural frequencies of the circular saw blade. The tensioning effect is enhanced with their increase. Dynamic characteristics can be regulated and controlled effectively by adjusting them.

Table 10.—Optimization schemes for multispot pressure tensioning process.

No.	Process parameters[a]					Natural frequency (Hz)					Average tangential tensile stress in the edge of circular saw blade (MPa)
	F (kN)	M	N	R_w (mm)	d (mm)	Nc = 0 Nd = 0	Nc = 0 Nd = 1	Nc = 0 Nd = 2	Nc = 0 Nd = 3	Nc = 0 Nd = 4	
1	80	4	16	150	30	62.07	56.98	113.38	252.19	433.36	129.14
2	80	4	16	130	20	46.49	57.64	123.43	278.53	480.73	110.24

[a] F = loading force; M = radial spot number; N = circumferential spot number; R_w = radius of spots in the outermost ring; d = radial distance; Nc = nodal circle; Nd = nodal diameter.

F and N have the smallest effects on the natural frequencies of the circular saw blade. The tensioning effect is enhanced with their increase in a small range. In general, it is not recommended to regulate and control the dynamic characteristics of the circular saw blade by adjusting them.

According to the range of average tangential tensile stress in the edge of the circular saw blade in Tables 5 through 9, F and M have the greatest effects on the average tangential tensile stress in the edge of the circular saw blade. Average tangential tensile stress in the edge of the circular saw blade is increased with them.

R_w has the second greatest effect on the average tangential tensile stress in the edge of the circular saw blade. Average tangential tensile stress in the edge of the circular saw blade is increased with it.

N and d have the smallest effects on the average tangential tensile stress in the edge of the circular saw blade, and could be ignored.

From the perspective of the average tangential tensile stress in the edge of the circular saw blade, according to the above analysis, F, M, N, R_w, and d are identified for its optimization. The average tangential tensile stress in the edge of the circular saw blade is the objective function. The greater the value of the average tangential tensile stress in the edge of the circular saw blade, the better. As shown in Tables 5 through 8, the process parameter configuration with $F = 80$ kN, $M = 4$, $N = 16$, $R_w = 150$ mm, and $d = 20$ mm can obtain the maximum average tangential tensile stress in the edge of the circular saw blade.

From the perspective of the natural frequency of the circular saw blade, according to the above analysis, F, M, N, R_w, and d are identified for its optimization. The natural frequency for Nc = 0 and Nd = 4 and natural frequency for Nc = 0 and Nd = 0 are the objective functions. The greater the natural frequency for Nc = 0 and Nd = 4, the better, under the premise that natural frequency for Nc = 0 and Nd = 0 is unchanged or decreased slightly. The process parameter configuration with $F = 80$ kN, $M = 4$, $N = 16$, $R_w = 130$ mm, and $d = 30$ mm can increase the natural frequency for Nc = 0 and Nd = 4 to a maximum degree, but can also reduce the natural frequency for Nc = 0 and Nd = 0 greatly. For example, as shown in Number 7 from Tables 3 and 4, the natural frequency of Nc = 0 and Nd = 0 is decreased greatly, which is called overtensioning.

Therefore, both the average tangential tensile stress in the edge of the circular saw blade and the natural frequency of Nc = 0 and Nd = 4 should be considered for the optimization of process parameters. $F = 80$ kN, $M = 4$, $N = 16$ can first be identified. There are two schemes for the optimization of a multispot pressure tensioning process, as shown below. If average tangential tensile stress in the edge of the circular saw blade is given priority, R_w is set as 150 mm. and d is set as 30 mm to ensure that the natural frequency of Nc = 0 and Nd = 4 does not decrease too much. If the natural frequency of Nc = 0 and Nd = 4 is given priority, R_w is set as 130 mm. The value of d is set as 20 mm to ensure that the average tangential tensile stress in the edge of the circular saw blade does not decrease too much.

As shown in Table 10, the two schemes for the optimization of a multispot pressure tensioning process could obtain both reasonable natural frequencies and average tangential tensile stress in the edge of the circular saw blade.

Conclusions

Elastic plastic deformation, linear elastic unloading, and modal analysis models of the circular saw blade tensioned by multispot pressure were built by ABAQUS software. The effects of process parameters on the natural frequency and tangential tensile stress in the edge of the circular saw blade were examined and compared. Considering the natural frequency and tangential tensile stress in the edge of the circular saw blade synthetically, optimal process parameters for multispot pressure tensioning were obtained based on the orthogonal method.

Simulation results show that R_w has the greatest effect on the natural frequencies of the circular saw blade. M and d have the second greatest effects on the natural frequencies of the circular saw blade. The dynamic characteristics can be regulated and controlled effectively by adjusting them within the appropriate range. F and N have the smallest effects on the natural frequencies of the circular saw blade. Regulation and control of the dynamic characteristics of the circular saw blade by adjusting F and N is not recommended.

Simulation results show that F and M have the greatest effects on tangential tensile stress in the edge of the circular saw blade. Tangential tensile stress in the edge of the circular saw blade is increased with these factors. R_w has the second greatest effect on tangential tensile stress in the edge of the circular saw blade. Tangential tensile stress in the edge of the circular saw blade is increased with it. Finally, d and N have the smallest effects on tangential tensile stress in the edge of the circular saw blade, and can be ignored. Tangential tensile stress in the edge of the circular saw blade can be regulated and controlled effectively by adjusting F after R_w, M, and d are determined.

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