Peening Intensity and Coverage Estimated by Simulation for Automotive Coil Spring

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Abstract
The peening intensity and coverage is simulated by DEFORM® for the conventional shot peening facilities. Peening facilities are selected by two types; the one is the horizontal-type and the spring is free to move through the shot tunnel. The other is the turret-type and the spring is under the compression. Those facilities are conventionally used for the coil spring industry. Amen® strip is attached in the coil spring to measure the arc height and coverage under the current peening parameters. Passing the several springs with the strips into the peening tunnel or turret, the arc height and intensity will be measured and evaluated whether the peening parameters are adequate for the coil spring quality assurance. Typically, those facilities are very huge and therefore hard to freely change or optimize the peeing parameters. Instead, computer analysis model can be a useful and powerful tool. In this paper, the peening process are modelled and the results are compared with the measured data to show the validity of the simulation.

Keywords Automotive Coil Spring, Peening Intensity, Peening Coverage, DEFORM®

Introduction

Shot peening is a typical and important process for the improvement of product operating life in automotive industry. Especially, among those products, coil spring must have two or more shot peening processes for extremely high fatigue life expectation. As a tendency of lightweight design, coil spring, as is relatively light component in a car, also becomes lighter and therefore, the higher design stress would threaten its fatigue life reduction or failure.
With the spring design optimization to reduce the fatigue failure, shot peening process is also optimized by shot parameters such as a shot ball size, shape, material, blasting speed, angle and even peening time. Those parameter changes can be verified when the newly-peened coil spring will run the fatigue test directly. Practically, fatigue test takes several weeks to see its effect. The reason is that the shot peening facility is considered as the black-box and the change such as shot parameters can be indirectly checked by the fatigue test only. If the computer simulation model is purposely set for the peening facility, the improvement effect can be directly expected and therefore, reduce the cost and the time of fatigue tests. Also, the coil spring, which is newly designed, can be surely evaluated its fatigue performance before the real manufacturing.
The computer simulation model is set up for the conventional peening facilities made by Sinto® and Wheelabrator®. The peening performances are verified by the measurement and shows the validity of the analysis model. This result will be used for the improvement of fatigue life expectation of a newly-developed coil spring.

Peening Facilities to be Simulated

One of the peening facilities is installed in YOUNGWIRE by SINTO, Japan company. It still continued operating since 2016. The operation of the peening facility is briefly explained as follows; coil springs are continuously fed on one pair of the long liners, which are rotated at the same direction. It plays a role in rotating the coil springs on them. Shot balls are blasted by the impellers, which are rotated by the opposite direction. For coil spring, this facility is named as “First Peening” or just simply “Peening Process”.

The other peening facility is called “Second Peening” or “Stress Peening”, installed by Wheelabrator, Swiss company. It is already installed and continue operating. The operation is as follows; two coil springs simultaneously get into the cabinet by robot arms. In the cabinet, there are two sets of upper and lower holding fixtures. Between them, one coil spring is located by robot arm and subsequently, compressed by the upper holding fixture moving down. The door cabinet is closed and the two fixtures are rotated. Finally, the shot balls are blasted.

Several Assumptions for Computer Simulation

First and second peening facilities has an “impeller” type blasting mechanism. Typically, shot peening can be blasted by impeller and air-nozzle type. For coil spring in automotive suspension, impeller type is generally applied. But for the simulation, the impeller type is modelled as nozzle type. Two blasts are actually overlapped and shot balls in the region are collided each other. But in a simulation, each blast is applied sequentially, for example, upper blast is followed by lower one. These assumptions are quite sufficient for the current research level and also computational cost can be reduced.

Figure 1. Concept of the First Peening (Left) and the Second (Right) Facilities

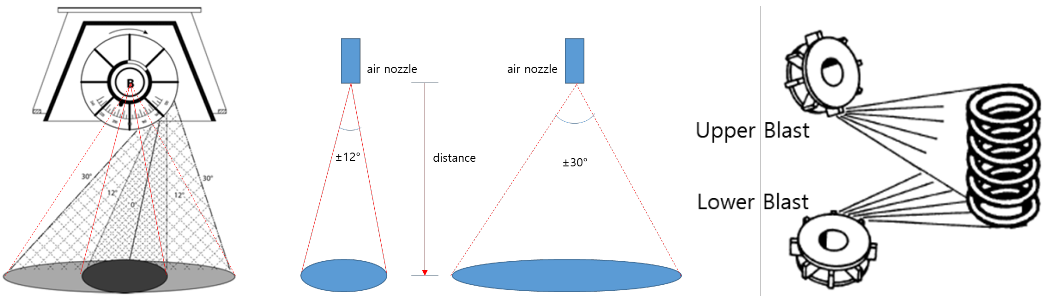


Figure 2. Assumption for Peening Simulation

Shot Peening Intensity and Coverage : Simulation and Measurement in Coil Springs

Shot peening is very important process for fatigue life of the coil spring. And therefore, it is necessary to measure the performance of the process for the spring to have a uniform quality of the peening. Practically, Almen Strip is fixed in coil spring and checked the arc height and the surface of the peened Almen strip. The arc height will become higher as a peening time is increased and eventually be saturated. The part of the peened surface of the Almen strip will be also increased and saturated. In a manufacturing point of view, the peening time must be reduced and also the peened coil spring must be satisfied by the fatigue test. That is, the peening time will be set by the coil spring design requirement and the manufacturing cost or cycle time in a factory.

For the coverage of the peening, the several samples of the peened Almen strips are prepared in advance. Those samples are specified by 100%, 90%, 70% etc. The newly-peened Almen strip is compared by the samples through the image analysis. The practical measurement of the peening intensity and coverage is based on the fatigue test of the coil spring and the ready-made samples.

In simulation, the coverage[1] is calculated by Eq. 1.

$$C = 100\{1-\exp(-\pi r2Rt)\} \quad (1)$$

where r is the radius of each impression, R is the uniform rate of creation of impressions and t is the time during which the impressions were being created.

From Eq. 1, the coverage can be changed from 0 to 100%. The simulation results in a theoretical coverage based on the size of the impression by 2D micro model.

The arc height can be estimated by “spring-back” analysis from the simulation. More specifically, the residual stress obtained from the simulation is the input for the spring-back analysis and the final elastic shape of the Almen strip or arc height can be calculated to satisfy the force equilibrium. The arc height from the simulation is directly compared with the measured value to show the simulation validity.

Shot Peening Simulation Procedure

Shot peening is simulated by three steps; axis-symmetric finite element analysis of 2D micro model, data analysis from the 2D micro model analysis, and impact simulation of the shot peening process.

First, 2D micro model simulation is performed to get the fundamental residual stress analysis. The impeller will accelerate shot balls to certain shot speed and hit on the surface. They will hit on the surface of the spring as an arbitrary angle, δ. And a specific region will be hit by any number of shot balls. To consider the angle and the hit number cases, 2D micro analyses are performed and the results are shown in Figure 4. As the increase of the number of hits, the minimum residual stresses are located in deeper, and the cross points are also deeper from the surface. As the increase of the hit angle, the residual stress is also increased as magnitude manner.

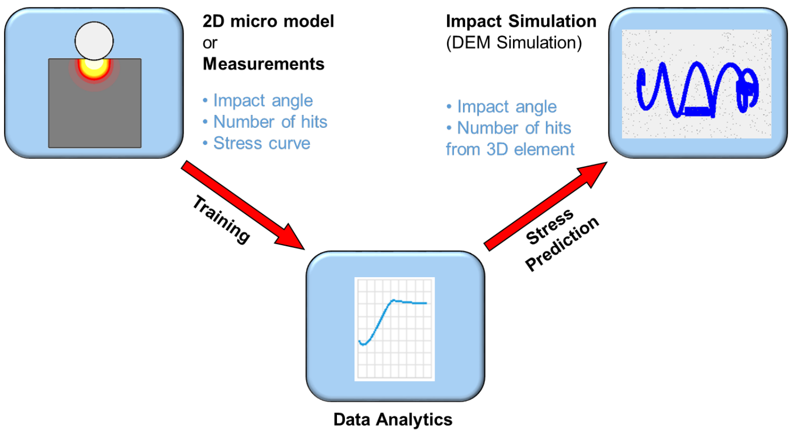


Figure 3. Shot Peening Simulation Procedure and Coil Spring Mesh Generation

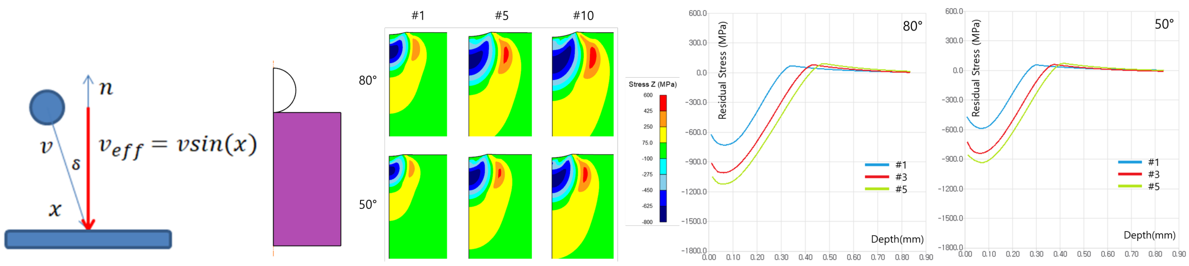


Figure 4. Analysis of the Data obtained by 2D micro model simulation

Finite Element Modelling of the Coil Spring and 2D Micro Model Simulation

The material of coil spring has flow stress as Eq. (2)

$$\bar{\sigma} = 607\bar{\varepsilon}^{0.23} + 1800 \tag{2}$$

The elastic material constants are that Young’s modulus is 210 GPa and Possion’s ratio is considered as 0.3. Shot ball diameter is 1mm and its velocity is 62 m/s, which is calculated by the impeller rotational speed and the radius. Coil spring is modelled by tetra elements as much as 800,000. The surface is fine-meshed to apply for accurate residual stress prediction in the depth since the residual stress varies greatly from the surface to less than 0.6mm as shown in Figure 6(a).

First Peening Simulation Results and Case Studies

Coil spring actually moves through the shot stream generated by the impeller. In simulation, the nozzle moves reversely with shot velocity 127mm/s, stream angle 50 degree and mass flow rate 1200 kg/min.

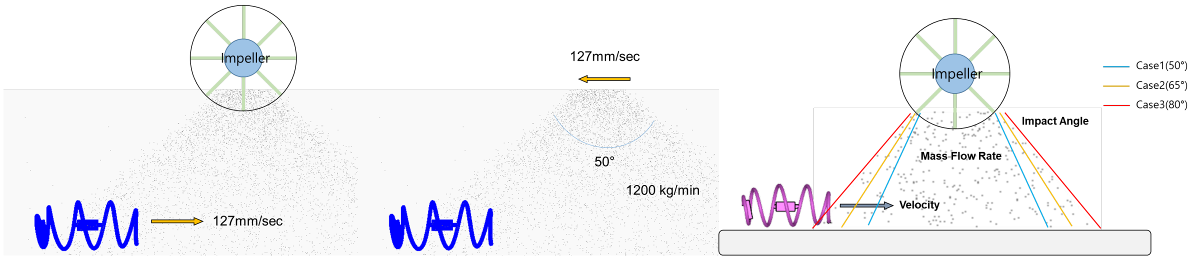
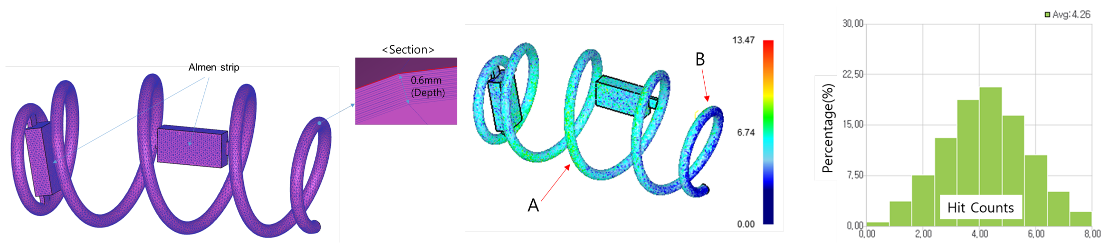
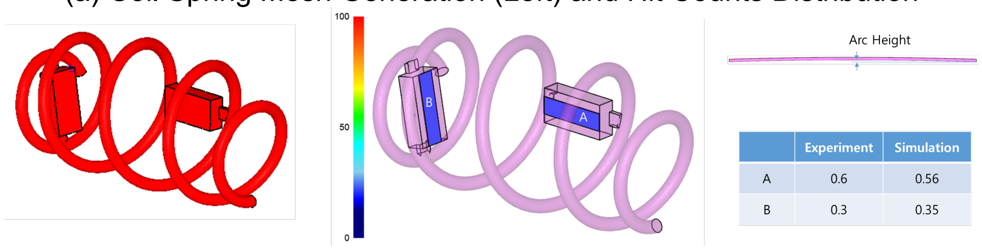


Figure 5. First Peening Simulation Boundary Conditions and Case Studies (Right)

Impact simulation results are shown in Figure 6(a). The average hit counts are 4.26 per unit area. Although this data may be hardly validated by the actual test, hit counts in the central area (A) is higher than in the upper or the lower area (B) in the coil spring. This phenomenon is expected since the shot ball stream from the impeller is perpendicular to the coil spring axis. It is a good information that there may exist some weak area in which the hit counts lower than 2. The region where hit counts are over 6 can be dangerous due to over-peening. The expected coverage is 100% in the entire surface as shown in Figure 6(b). The coverage is calculated by Eq. 1. The arc height of the Almen strip is compared with the ones from actual test data. For central and upper part of the coil spring, the actual arc heights are 0.6 and 0.3 mm. The spring-back analysis after the impact simulation will expect as 0.56 and 0.35 mm. It shows the current peening analysis can be used to optimize the peing process.



(a) Coil Spring Mesh Generation (Left) and Hit Counts Distribution



	Experiment	Simulation
A	0.6	0.56
B	0.3	0.35

(b) Coverage and arc height

Figure 6. First Peening Simulation Results

Several peening parameters are considered as shown in Figure 5. The parameters are spray angle , mass flow rate and movement speed. Physically, the higher mass flow rate and movement speed, the lower hit counts. As the spring angle becomes obtuse, usable hit counts may be lower.

When the movement speed changes as 106, 127 and 152 mm/s with spring angle 65 degree and mass flow 1200 kg/min fixed, the results are shown in Figure 7. The average hit count is decreased as 2.31, 1.93 and 1.57. The results for other cases are shown in Figure 7.

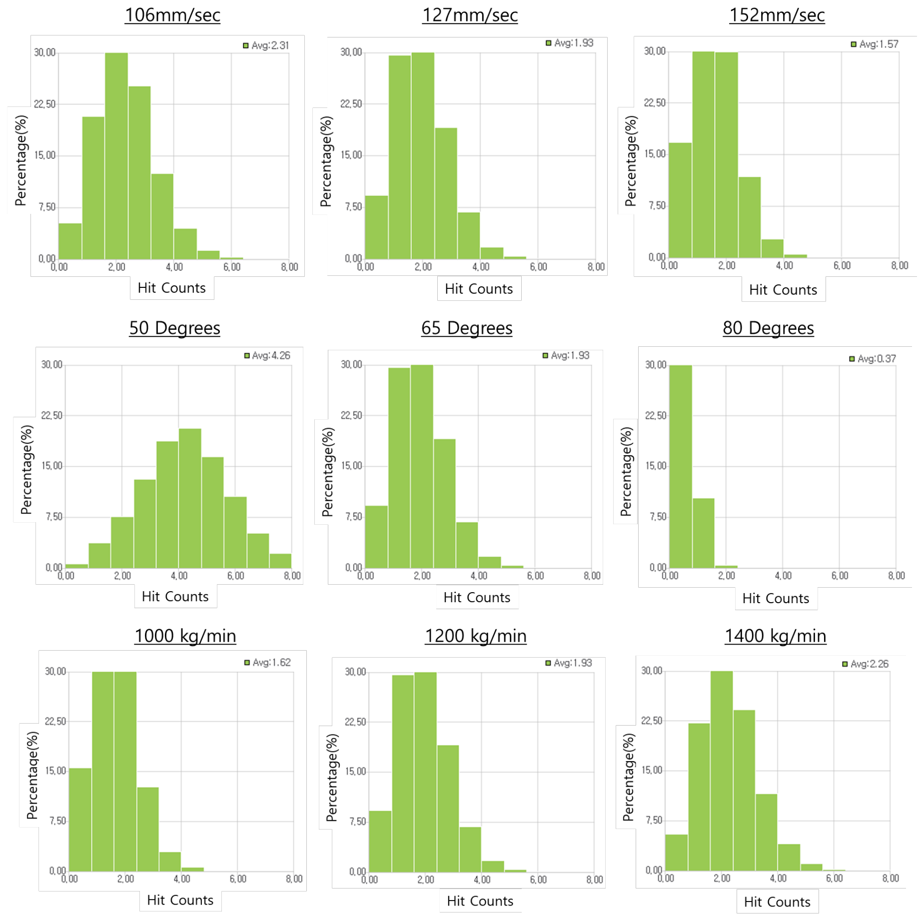


Figure 7. Case Studies Results of the First Peening

The coverage is 100% for all cases except 80 degrees. 25% area on the coil spring surface shows the coverage 0%. This is extreme case and does not happen in a coil spring manufacturing. But the simulation says if the spray angle cannot be controlled, the coverage is degraded and the coil spring must have a problem.

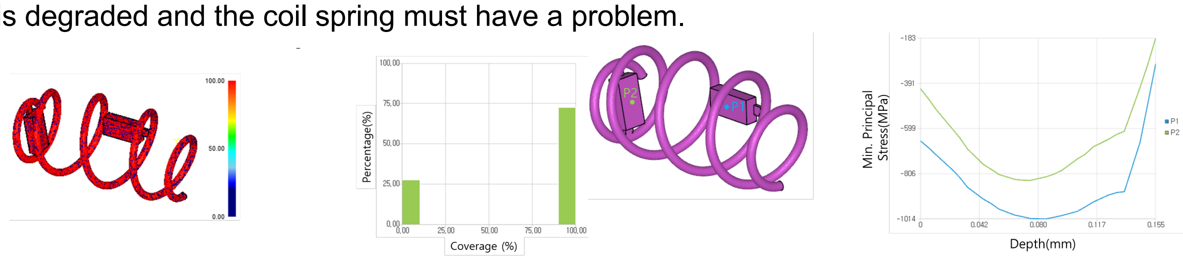


Figure 8. Extreme Case with Spray Angle 80 degree and Residual Stress at 65 Degree

The impact simulation can predict the residual stress based on 2D micro model and data analysis. The minimum principal stress is -1,014 MPa for central part in the coil spring. The residual stresses also show that the upper part of the coil spring tends to become weaker than the central part and this phenomenon is the same as the hit count density.

Second Peening Simulation

For stress peening simulation, the compressed coil spring model shape is applied with mass flow rate 350 kg/min, rotational speed 3 rad/s and process time 7 seconds. Although two impellers is actually located in the upper and the lower of the coil spring as shown in Figure 2, only one impeller is first applied due to analysis error, not converged issue.

Average hit counts in the stress peening is 70.04, which is very higher than 4.26 in first peening. In stress peening process, the distance between the coil spring and the impellers is shorter and the spray angle is more acute than first peening. The coverage is 100% except the lower part of the coil spring.

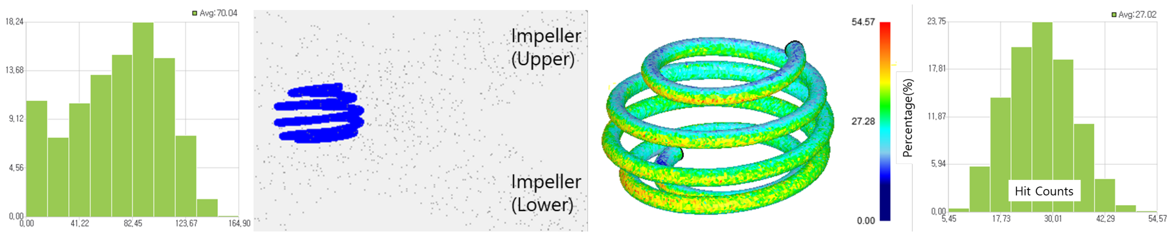


Figure 9. Stress Peening with Two impellers

To consider two impellers to shot the ball to the coil spring, mass flow rate is reduced to 85 kg/min for converged solution. The rotational speed is 3 rad/s and peening time is 6 seconds. The average hit count is 27.02, which is lower than one impeller case since the mass flow rate is decreased.

Conclusions and Discussions

Shot peening simulation was implemented to predict the peening intensity and coverage of the actual peening processes; first and stress peening. The commercial software, DEFORM, is used to model the process by three steps; 2D micro model, data analysis and impact simulation.

The arc height of Almen strip from simulation is correlated very accurately by comparing it with the experimental data. The coverage is also good correlated by actual visual inspection. From the simulation results, it is noted as follows;

1) The upper or the lower part of the coil spring tends to become easily weaker than the remaining part of the spring.

2) As the peening velocity and impact angle is increased, the hit counts will be decreased. Conversely, as the mass flow rate is increased, the hit counts are increased

3) The distribution of the hit counts tends to become “Normal Distribution”.

Although the above information is amazingly interesting us, it should be improved as follows;

1) Residual stress from impact analysis for both peenings simulation shows a little unreasonable value locally.

2) Stress peening simulation does not consider the compression of the coil spring during the peening, but the compressed shape.

3) Current simulation deals with first and second peening separately but in fact, the second peeing is followed by the first one and therefore, in simulation, this must be considered.

Nevertheless, we think that the peening simulation by DEFORM® is reasonable and can be used for the optimization of the peening parameters for the conventional peening facilities. Some problems in the current version of the simulation can be soon fixed by the software development company and overcome by YOUNGWIRE engineer.

Acknowledgement

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