

# RecurDyn Contact 알고 쓰면 쉬워요!

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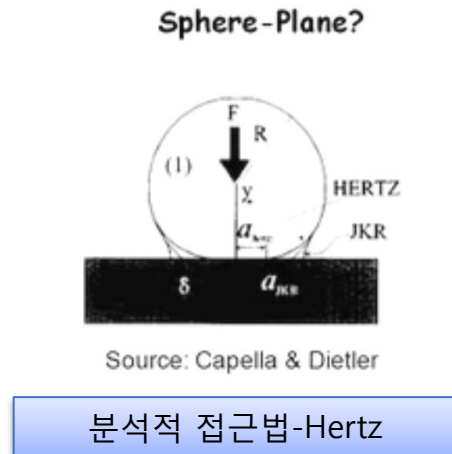
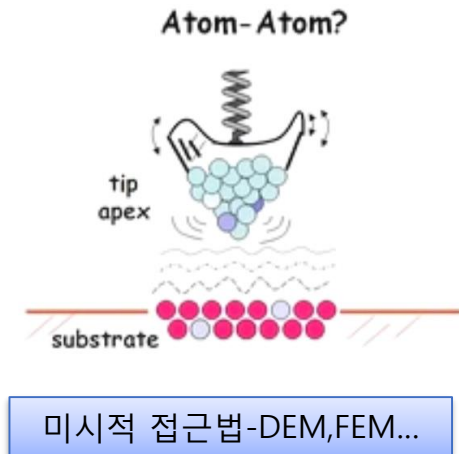
1. 접촉 모델링의 단계별 가이드

## IV. CASE study

# 접촉 모델에 대해...

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# 접촉해석에 대한 접근방법



Ueber die Berührung fester elastischer Körper.  
(Von Herrn Heinrich Hertz.)

In der Theorie der Elasticität werden als Ursachen der Deformationen theils Kräfte, welche auf das Innere der Körper wirken, theils auf die Oberfläche wirkende Druckkräfte angenommen. Für beide Arten von Kräften kann der Fall eintreten, dass dieselben in einzelnen unendlich kleinen Theilen der Körper unendlich gross werden, so zwar, dass die Integrale der Kräfte über diese Theile genommen einen endlichen Werth behalten. Beschreiben wir alsdann um den Unstetigkeitspunkt eine geschlossene Fläche, deren Dimensionen sehr klein gegen die Dimensionen des ganzen Körpers sind, sehr gross hingegen im Vergleich zu den Dimensionen des Theils, in welchem die Kräfte angreifen, so können die Deformationen ausserhalb und innerhalb dieser Fläche ganz unabhängig von einander betrachtet werden. Ausserhalb hängen die Deformationen ab von der Gestalt des Gesamtkörpers, der Vertheilung der übrigen Kräfte und den endlichen Integralen der Kraftcomponenten im Unstetigkeitspunkte, innerhalb hängen sie nur ab von der Vertheilung der im Innern selbst angreifenden Kräfte. Die Drucke und Deformationen im Innern sind gegen die im Aeussern unendlich gross.

In Folgenden wollen wir einen hierher gehörigen Fall behandeln, der praktisches Interesse hat\*, den Fall nämlich, dass zwei elastische isotope Körper sich in einem sehr kleinen Theil ihrer Oberfläche berühren, und durch diesen Theil einen endlichen Druck der eine auf den andern ausüben. Die sich berührenden Oberflächen stellen wir uns als vollkommen glatt vor, d. h. wir nehmen nur einen senkrechten Druck zwischen den sich berührenden Theilen an. Das beiden Körpern nach der Deformation gemeinsame Stück der Oberfläche wollen wir die Druckfläche, die Begrenzung

\*) Vgl. Winkler, Die Lehre von der Elasticität und Festigkeit, Prag 1867; I. p. 43. Grashof, Theorie der Elasticität und Festigkeit, Berlin 1878; p. 49-54.

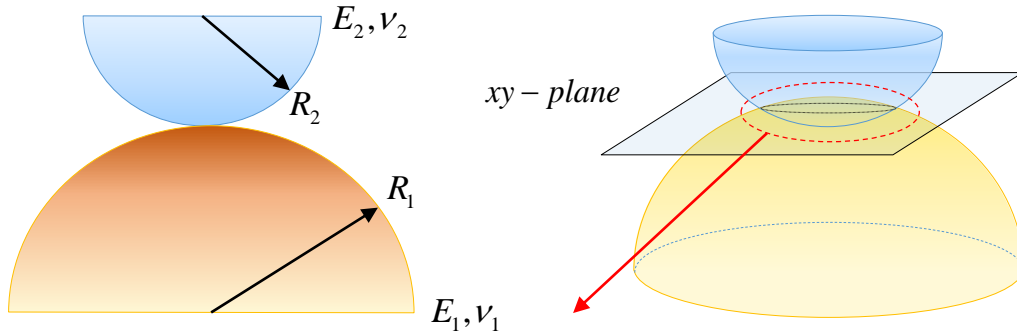
- 1881년 Heinrich Hertz에 의해 최초 제안 - 일반 형상과 응력 및 변형에 대한 해석적 접근
- 1932년 Bradley의 연구에 의해 두 강체 구의 접촉을 고려
- 1965년 Sneddon 에 의해 접촉 시 Half-space 탄성을 고려 하여 표면의 응력을 분석
- 1971년 Johnson-Kendall-Roberts에 의해 무른 소재의 접촉에서 발생하는 점착력(adhesion)고려
- 1975년 Derjaguin-Muller-Toporov에 의해 탄성 구와 강체 면의 접촉에 대해 van der Waals 힘을 고려
- 1992년 Maugis에 의해 기존의 점착력에 대한 연구를 향상하여 정확도를 높임

해석적 접근법은 최초 접촉이론이 개발된 이래로 기본적인 해석이론에 대해 큰 변화가 없으며 점착력이나 분자력과 같은 보다 미시적 현상에 대한 연구가 주로 이루어 졌음

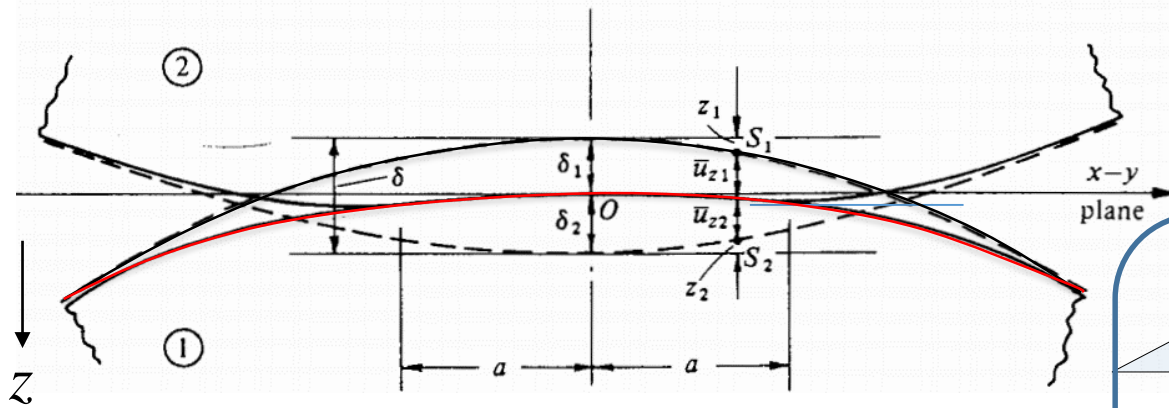
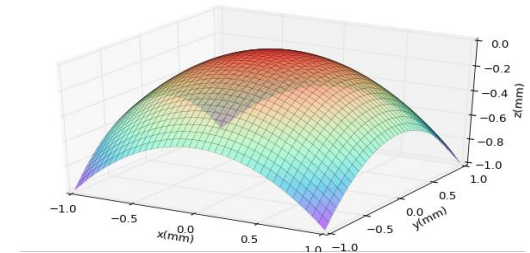
※ Purdue University Lecture 8 Introduction to Contact Mechanics

# Hertz contact model

## 접촉상황 및 변형 형상에 대한 가정



Shape function of  $z$

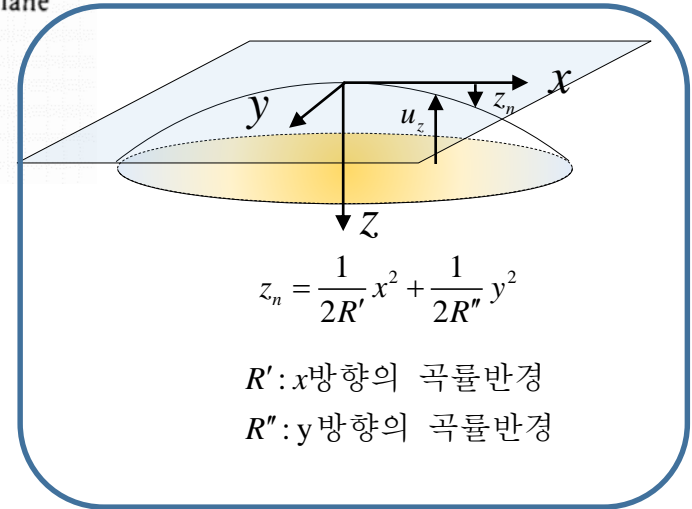


$$h = z_1 - z_2$$

$$z_1 = \frac{1}{2R'_1} x^2 + \frac{1}{2R''_1} y^2$$

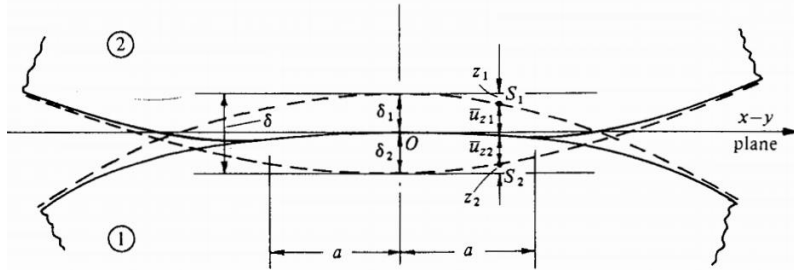
$$\bar{u}_{z1} + \bar{u}_{z2} + h = \delta_1 + \delta_2$$

$$z_2 = -\left( \frac{1}{2R'_2} x^2 + \frac{1}{2R''_2} y^2 \right)$$

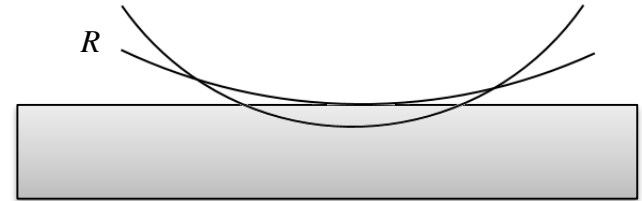


# Hertz contact model

## 함수 h에 대한 단순화



단순화



$$h = Ax^2 + By^2 = \frac{1}{2R}x^2 + \frac{1}{2R}y^2$$

$$h = z_1 - z_2 = \frac{1}{2R'_1}x^2 + \frac{1}{2R''_1}y^2 + \frac{1}{2R'_2}x^2 + \frac{1}{2R''_2}y^2$$

where,  $R'_1 = R''_1 = R_1$ ,  $R'_2 = R''_2 = R_2$

$$h = \frac{1}{2} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) x^2 + \frac{1}{2} \left( \frac{1}{R_1} + \frac{1}{R_2} \right) y^2$$

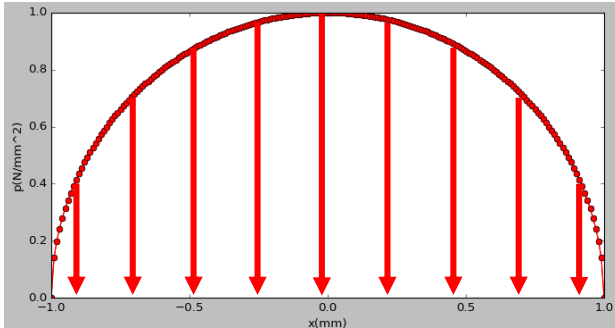
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

## 함수 h를 r-θ좌표계에 대해 표현

$$h = \frac{1}{2R}x^2 + \frac{1}{2R}y^2 \Rightarrow \frac{1}{2R}r^2 \quad (r-\theta \text{ coordinate})$$

# Hertz contact model

## 접촉면의 압력형상 가정



압력의 분포가 반구형으로 작용한다고 가정

$$p(r) = p_0 \sqrt{a^2 - r^2} / a$$

압력의 분포가 반구형으로 작용한다고 가정했을 경우 반경 r에 대한 z변위의 계산식 (응력과 변형률 계산공식으로부터 도출)

$$\bar{u}_{z1} + \bar{u}_{z2} = \delta_1 + \delta_2 - h$$

$$\bar{u}_{z1} + \bar{u}_{z2} = \delta - \frac{1}{2R} r^2 \quad (\delta = \delta_1 + \delta_2)$$

$$\begin{cases} \bar{u}_{z1} = \frac{1-\nu_1^2}{E_1} \frac{\pi p_0}{4a} (2a^2 - r^2) \\ \bar{u}_{z2} = \frac{1-\nu_2^2}{E_2} \frac{\pi p_0}{4a} (2a^2 - r^2) \end{cases}$$

$$\frac{1-\nu_1^2}{E_1} \frac{\pi p_0}{4a} (2a^2 - r^2) + \frac{1-\nu_2^2}{E_2} \frac{\pi p_0}{4a} (2a^2 - r^2) = \delta - \frac{1}{2R} r^2 \quad (\delta = \delta_1 + \delta_2)$$

# Hertz contact model

$$\frac{\pi p_0}{4a} (2a^2 - r^2) \left( \frac{1 - \nu_1^2}{E_1} + \frac{1 - \nu_2^2}{E_2} \right) = \delta - \frac{1}{2R} r^2$$

$$\frac{\pi p_0}{4aE} (2a^2 - r^2) = \delta - \frac{1}{2R} r^2$$

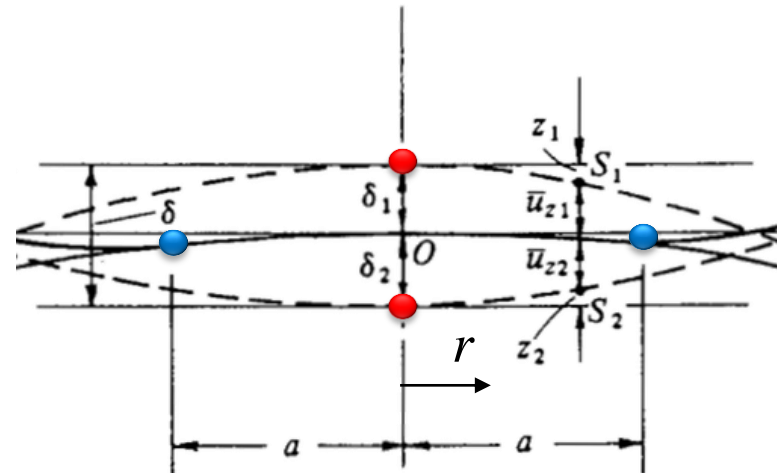
$$\left( \frac{1}{E} = \frac{1 - \nu_1^2}{E_1} + \frac{1 - \nu_2^2}{E_2} \right)$$

## 경계조건 적용

r이 0일 때의  $\delta$ 를 변형량으로 결정  
 r=a일 때 평형관계식을 통해 a를 결정

where,  $r = 0$  then,  $\delta = \frac{\pi p_0 a}{2E}$

where,  $r = a, \delta = 0$  then,  $a = \frac{\pi p_0 R}{2E}$





# Hertz contact model

원인 접촉면에 반구 형상의 압력(p)이 가해질 경우 전체 하중 P 계산

$$P = \int_0^a 2\pi r \cdot p(r) dr = \frac{2\pi p_0}{a} \int_0^a r \sqrt{a^2 - r^2} dr = \frac{2}{3} \pi p_0 a^2$$

$$P = \frac{2}{3} \pi p_0 a^2 \longrightarrow p_0 = \frac{3P}{2\pi a^2}$$

변형량과 접촉길이의 식에 P의 관계식 대입

$$\delta = \frac{\pi p_0 a}{2E}, \quad a = \frac{\pi p_0 R}{2E}$$

$$a = \frac{\pi p_0 R}{2E} = \frac{3PR}{4Ea^2} \quad \left( \text{where, } p_0 = \frac{3P}{2\pi a^2} \right)$$

$$\delta = \frac{a^2}{R} = \frac{1}{R} \left( \frac{3PR}{4E} \right)^{2/3} = \left( \frac{9P^2}{16RE^2} \right)^{1/3}$$

$$p_0 = \frac{3P}{2\pi a^2} = \left( \frac{6PE^2}{\pi^3 R^2} \right)^{1/3}$$

$$\therefore a = \left( \frac{3PR}{4E} \right)^{1/3}, \quad \delta = \left( \frac{9P^2}{16RE^2} \right)^{1/3}, \quad p_0 = \left( \frac{6PE^2}{\pi^3 R^2} \right)^{1/3}$$

# Hertz contact model

Hertz Contact Formulation

$$P = \sqrt{\frac{16RE^2}{9}} \delta^{3/2} = K \cdot \delta^{1.5}$$

$$R = \frac{R_1 R_2}{R_1 + R_2}$$

$$K = \sqrt{\frac{16RE^2}{9}}$$

$$E = \frac{E_1 E_2}{E_2 (1 - \nu_1^2) + E_1 (1 - \nu_2^2)}$$

RecurDyn Contact Formulation

$$F = K \cdot \delta^n$$

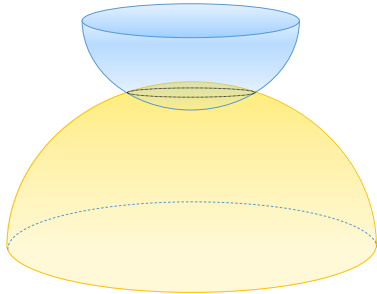
$$K = f(R_1, R_2, E_1, E_2, \nu_1, \nu_2)$$
$$n = 1.5$$

## References

- H. Hertz, “Über die Berührung fester elastischer Körper,” Gesammelte Werke (P. Lenard, ed.), Bd. 1, (J.A. Barth, Leipzig, 1895) pp. 155-173. Originally published in Journal f. d. reine u. angewandte Mathematik 92, 156-171 (1881).
- ‘Contact mechanics’ in Wikipedia
- R S Dwyer-Joyce, “Tribological Design Data Part 3: Contact Mechanics” University of Sheffield
- K.L. Johnson, “Contact Mechanics” Cambridge University Press 1985 ISBN 0 521 347963
- Georges Cailletaud, Stéphanie Basseville, Vladislav A. Yastrebov, “Contact mechanics I: basics”, EMESURF short course on contact mechanics and tribology, Paris, France, 21-24 June 2010
- <https://woodem.org/theory/contact/hertzian.html>

# Hertz contact model – parameters

- 구와 구가 접촉하는 상황에 대해 다양한 반경 적용(Steel)



- E1,E2=210Gpa
- E = 115Gpa
- ν1, ν2=0.3

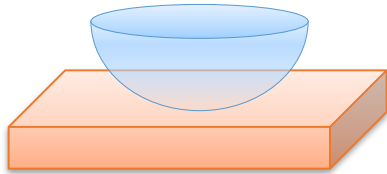
$$R = \frac{R_1 R_2}{R_1 + R_2} \quad K = \sqrt{\frac{16 R E^2}{9}}$$

$$E = \frac{E_1 E_2}{E_2 (1 - \nu_1^2) + E_1 (1 - \nu_2^2)}$$

R1(mm)	R2(mm)	R	K	MMKS
0.5	1	0.333333333	88823	
0.5	10	0.476190476	106163	
0.5	100	0.497512438	108514	
0.5	1000	0.499750125	108758	
0.5	10000	0.499975001	108782	
0.5	100000	0.4999975	108785	
0.5	1000000	0.49999975	108785	

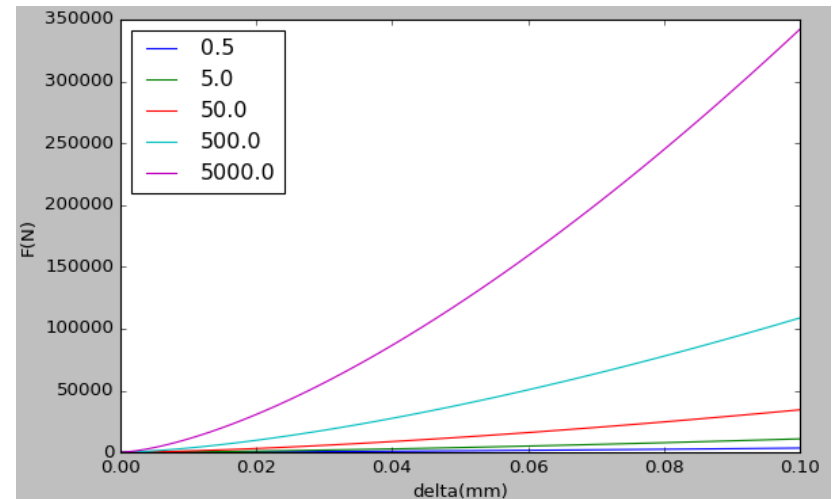
RecurDyn Default value = 100000

- 구와 평면이 접촉하는 상황에 대해 다양한 반경 적용(Steel)



- E1,E2=210Gpa
- E = 115Gpa
- ν1, ν2=0.3

R1(mm)	R2(mm)	R	K
0.5	500000	0.4999995	108785
5	500000	4.99995	344008
50	500000	49.9950005	1087802
500	500000	499.5004995	3438385
5000	500000	4950.49505	10824577



Hertz Contact FD curve

# Hertz contact model – parameters

- 다양한 소재에 대한 접촉 물성치 적용

Material Properties

Material	E(Gpa)	$\nu$
Steel	210.00	0.3
Aluminum	70.00	0.32
Bronze	120.00	0.34
Oak Wood	11.00	0.35
Plastic	2.40	0.39
Rubber(EPDM)	0.02	0.5

R1=0.5mm ,R2=500000mm

	Steel	Aluminum	Bronze	Oak Wood	Plastic	Rubber
Steel	108786	54955	80559	11210	2636	25
Aluminum		36763	46690	10182	2575	25
Bronze			63963	10819	2614	25
Oak Wood				5909	2177	25
Plastic					1334	25
Rubber						13

Contact Stiffness K for MMKS Model

## ● Conclusion

- ▣ Hertz Contact 모델을 이용한 접촉해석에서 Stiffness(K)의 값은 두 소재의 탄성계수(Young's Modulus)와 두 Solid의 접촉면에서 형상에 대한 곡률반경을 이용하여 구할 수 있다.

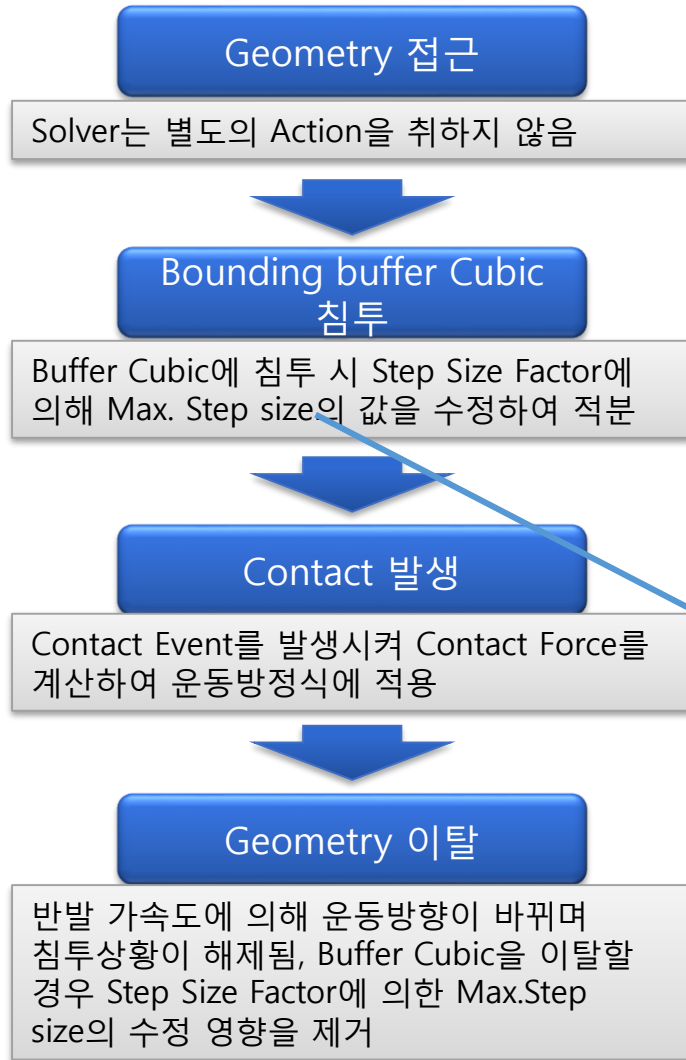
$$K = \sqrt{\frac{16RE^2}{9}}$$

$$\left\{ \begin{array}{l} R = \frac{R_1 R_2}{R_1 + R_2} \\ E = \frac{E_1 E_2}{E_2 (1 - \nu_1^2) + E_1 (1 - \nu_2^2)} \end{array} \right.$$

# RecurDyn Contact

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# RecurDyn Contact Computing process



Properties of GeoSurContact1 [ Current Unit : N/kg/mm/s/deg ]

General Characteristic **Geo Contact**

Type: Standard Contact Force

Characteristic

Spring Coefficient: 100000 Pv

Damping Coefficient: 10 Pv

Dynamic Friction Coefficient: 0 Pv Friction

Stiffness Exponent: 2 Pv

Indentation Exponent

Boundary Penetration

Boundary Penetration: 1.e-002 Pv

Rebound Damping Factor: 0.25 Pv

Maximum Penetration: 0.8 Pv

**Maximum Stepsize Factor: 2 Pv**

Scope OK Cancel Apply

Buffer Cubic

# RecurDyn Contact formula

- Normal Force

$$f_n = f_{ns} + f_{nd} \quad \begin{cases} f_{ns} : \text{stiffness force of contact} \\ f_{nd} : \text{damping force of contact} \end{cases}$$

- Stiffness Force: Hertz Contact이론에 기반한 수식 사용

$$f_{ns} = K \cdot \delta^{ms}$$

- Damping Force

- Boundary Penetration Method

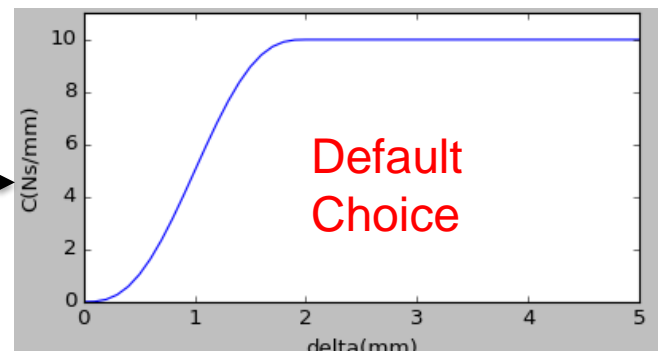
$$f_{nd} = \text{step}(\delta, 0, \delta_{\max}, C_{\max}) \cdot \dot{\delta}$$

- Indentation Exponent Method

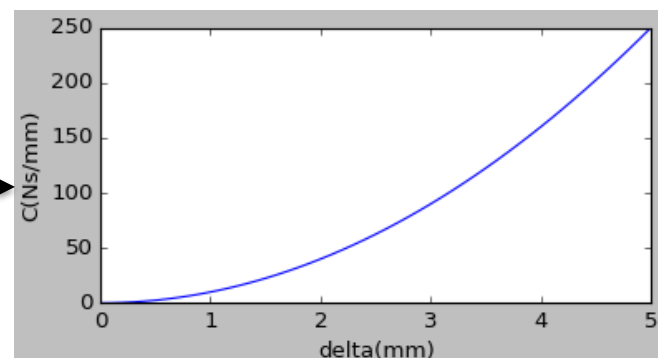
$$f_{nd} = C_{\max} \cdot \delta^{mi} \cdot \text{sgn}(\dot{\delta}) \cdot \dot{\delta}^{md}$$

default parameters:  $md = 1, mi = 2$

$$f_{nd} = C_{\max} \cdot \delta^2 \cdot \dot{\delta}$$



$\delta - c$  curve of BPM



$\delta - c$  curve of IEM

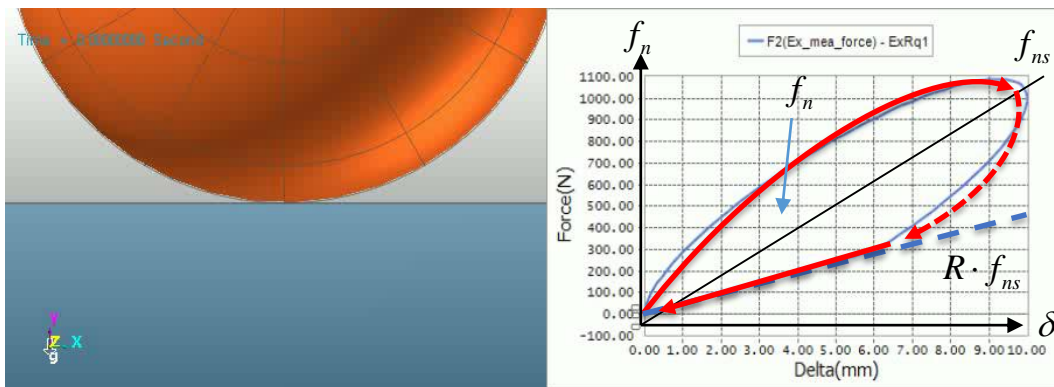
# RecurDyn Contact formula

## ❏ Damping Force (Cont.)

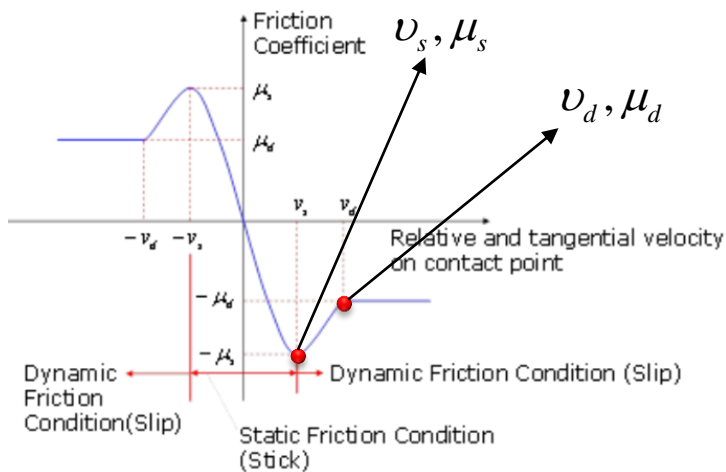
### ➤ Rebound Damping Factor

- ✓ 반발력의 방향은 침투할 때 밀어내는 방향이지만 이탈할 경우 잡아 당기는 방향
- ✓ 과도한 Damping이 작용할 경우  $f_s$ 보다  $f_d$ 가 커지는 점착 상황 발생
- ✓ 점착 상황을 방지하기 위해 Rebound Damping factor 사용

$$f_n = \max(f_n, R \cdot f_{ns})$$



## ● Friction Force



정마찰 및 동마찰 계수와 임계속도를 이용한 마찰특성그래프를 생성하고 이를 속도의 함수로 보간하여 사용

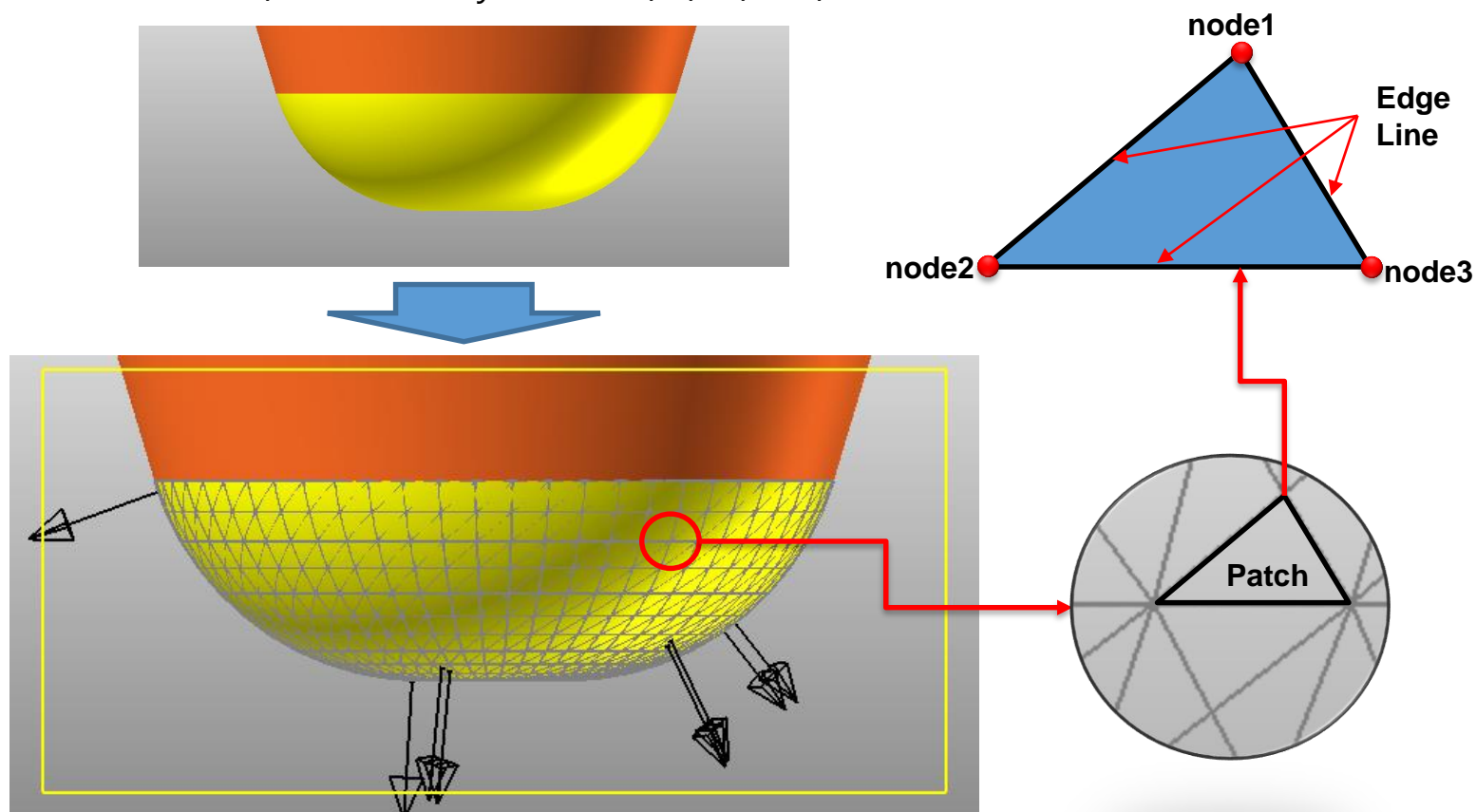


# Faceting

- Faceting

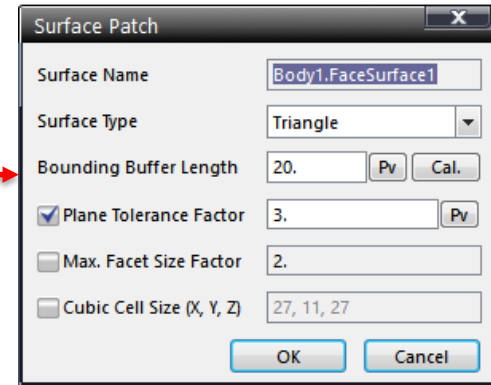
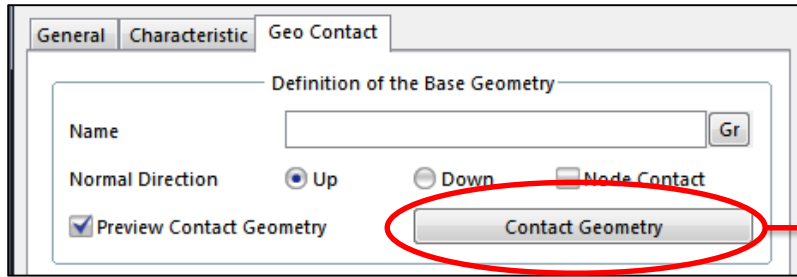
- ▣ 자유곡면을 수학적 연산이 용이한 3각형 Polygon으로 분할하는 작업

- 접촉연산을 수행할 때 곡면의 함수를 직접 이용할 경우 그 경우의 수와 함수의 복잡성으로 인해 계산속도가 급격하게 느려 질 수 있다. 이를 해결하기 위해 3각 Patch형태로 Geometry를 분할하여 계산에 활용



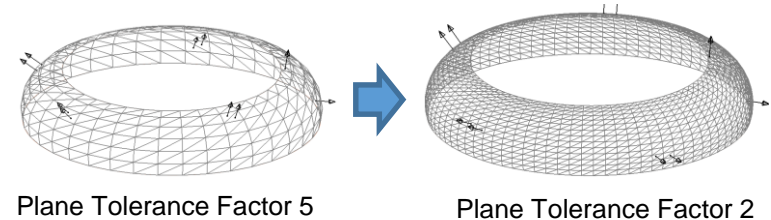
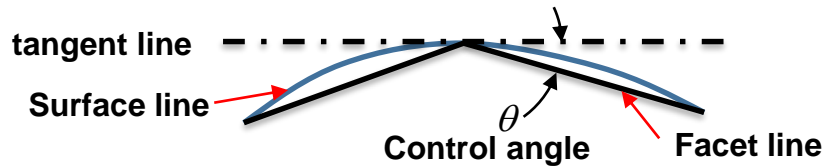
# Faceting

## Faceting control parameters



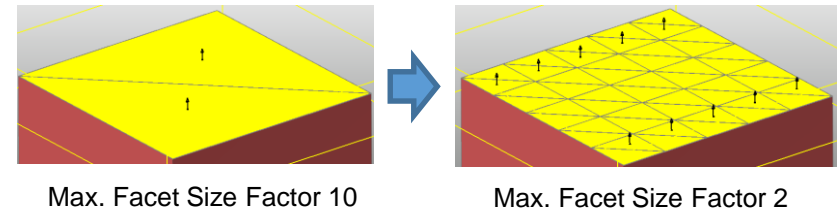
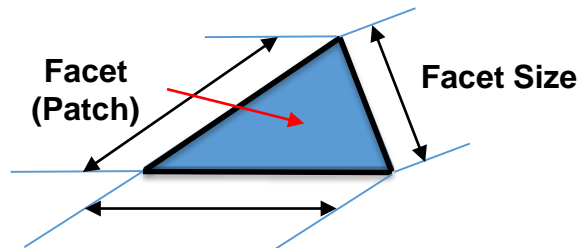
### Plane Tolerance Factor (0.01~10)

- 곡률을 분할하는 정도로서 값이 작을 수록 곡면에서 Facet의 개수가 많아짐



### Max. Facet Size Factor

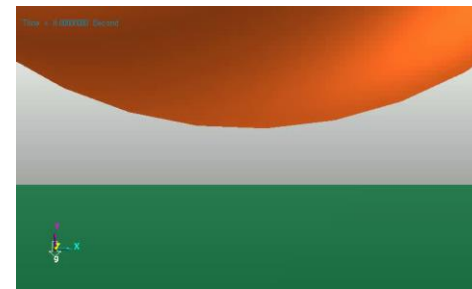
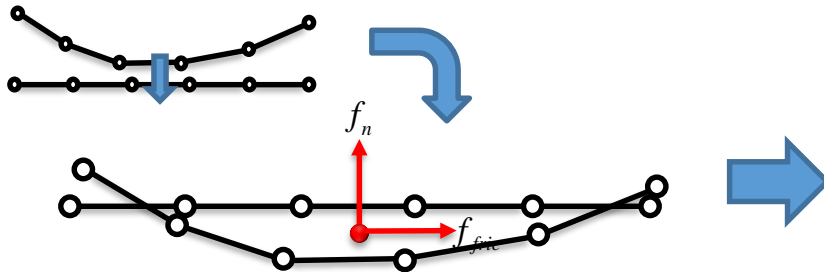
- Facet의 크기를 제한하는 Factor로서 작은 값 일 수록 면의 Facet개수가 많아짐



# Contact Event

- Solid contact – ( Solid contact )

- ▣ Patch들이 침투한 상황에서 대표점(Geometry Center)에서 접촉발생

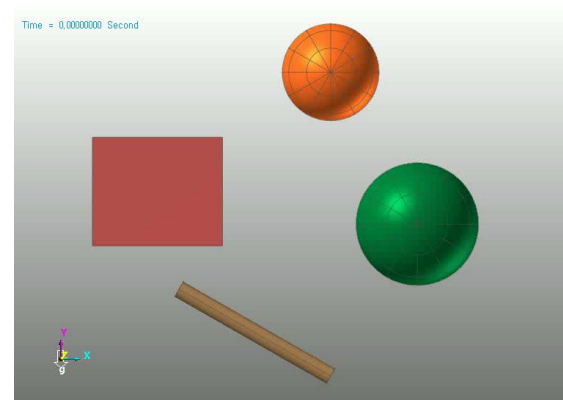
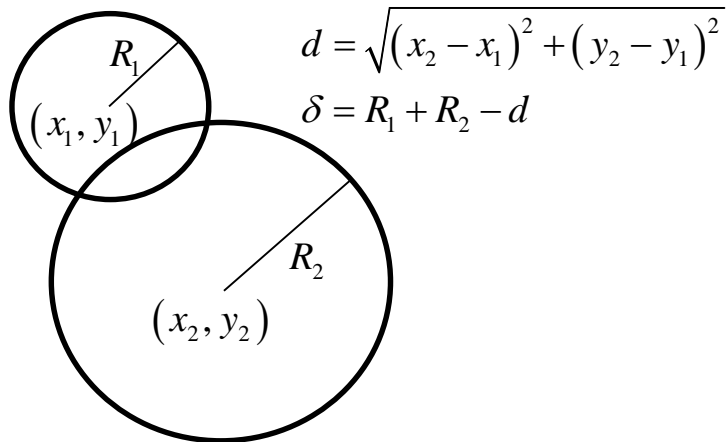


Simulation

- Analytical contact – ( Primitive contact )

- ▣ 미리 정의된 형상의 함수 식에서 접촉 위치를 계산하여 대표점에서 접촉

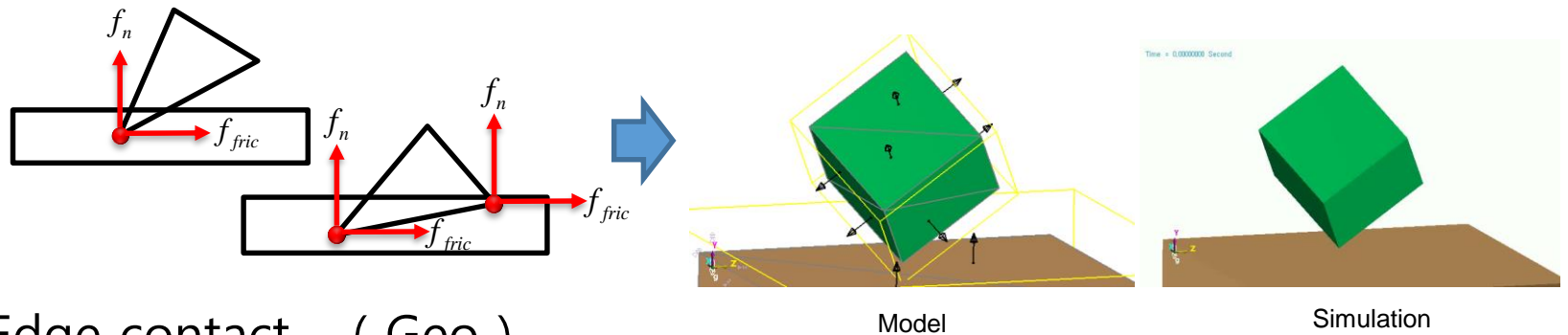
- ▣ Faceting을 수행하지 않으며 Patch도 존재하지 않음



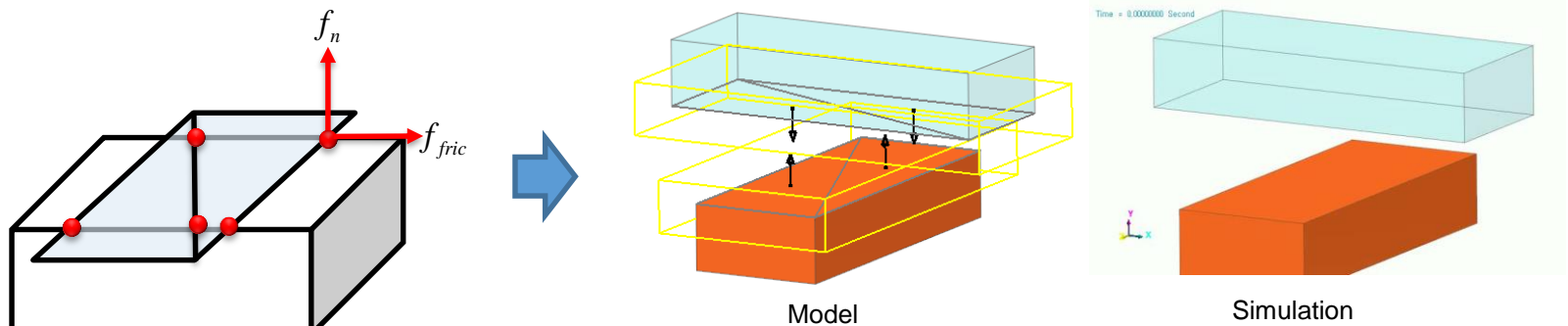
Simulation

# Contact Event

- Point(Node) contact – ( Geo contact, Surface contact)
  - ▣ Node의 각 점이 상대 Geometry의 Patch면에 침투(Penetration) 할 경우 접촉발생
  - ▣ node에서 상대 Geometry의 Patch에 침투 발생시 개별적으로 Contact발생

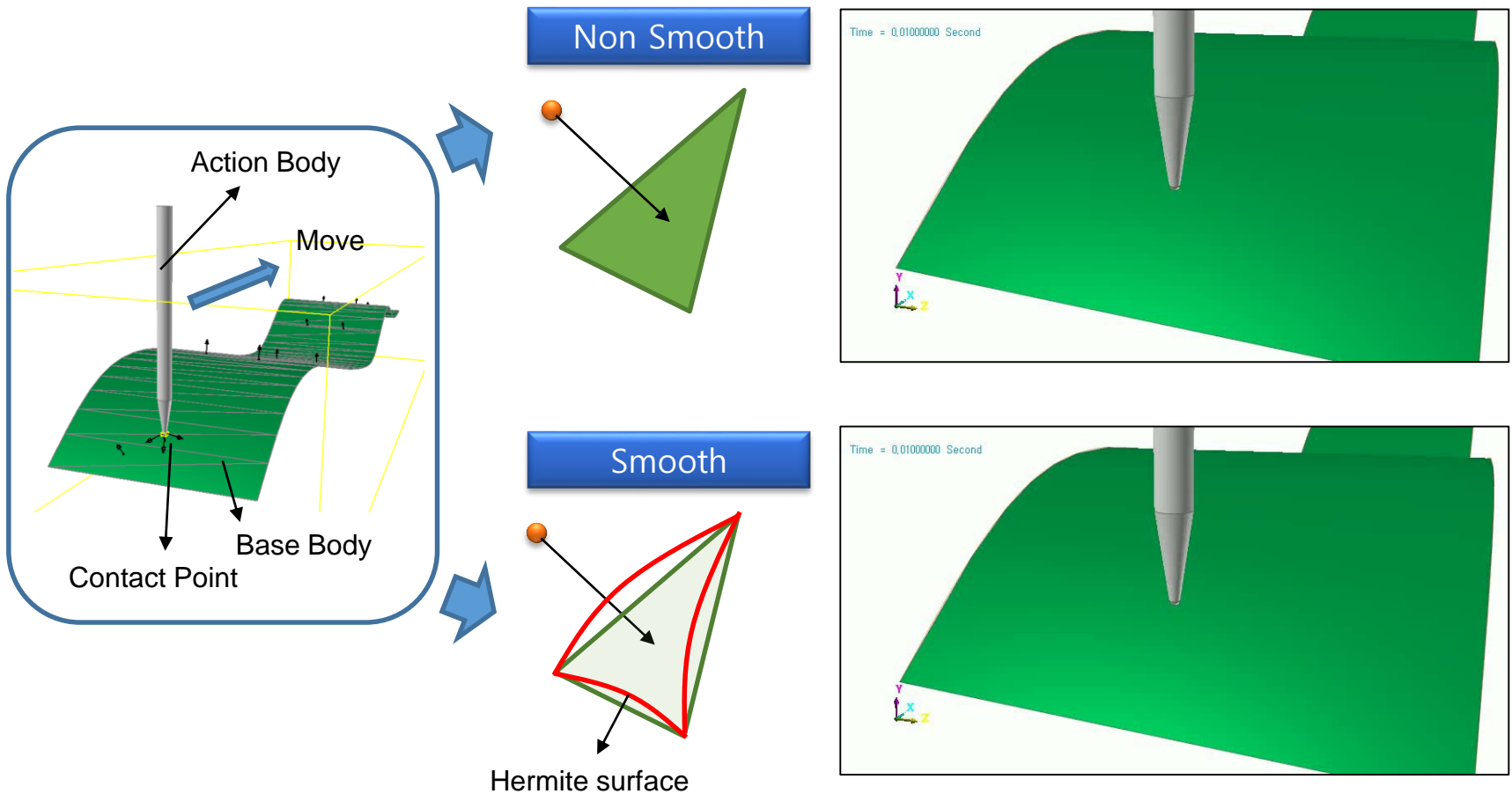


- Edge contact – ( Geo )
  - ▣ Patch의 외각 선인 Edge Line이 상대Patch의 Edge Line과 교차점에서 침투 할 경우 접촉발생



# Smooth Contact – Geo contact

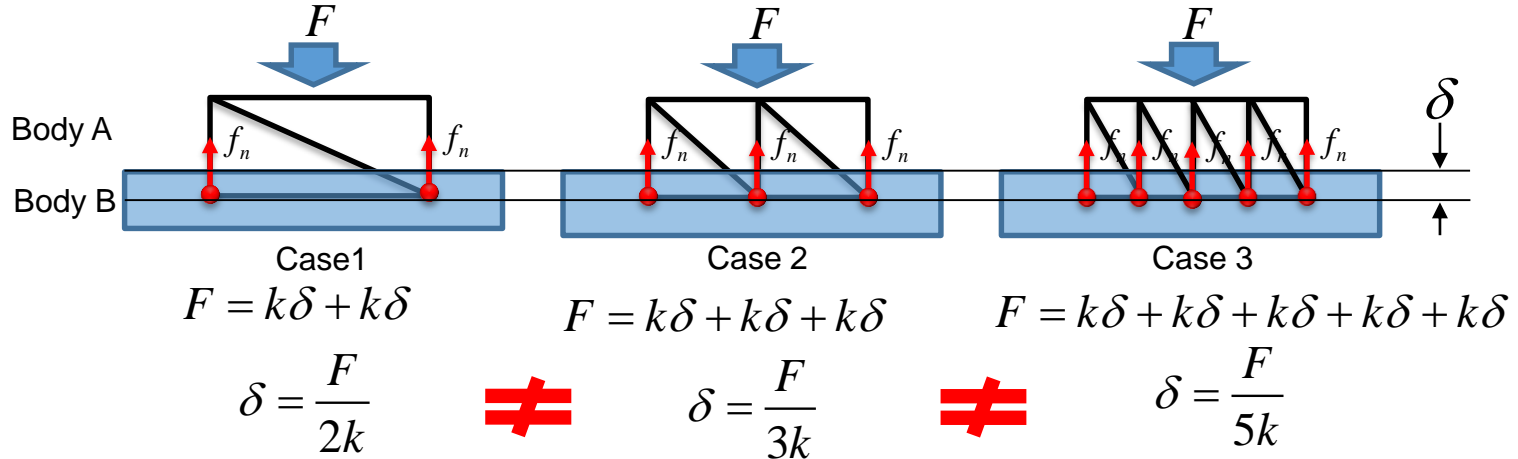
- Point contact event에서 Point의 상대 Patch의 면을 Hermite 곡면으로 변환하여 접촉을 계산하는 방법
  - ▣ Patch의 절점에서 불연속 면이 사라지는 효과
  - ▣ Geo Contact에서만 사용가능



# CPM – Geo contact

- CPM(consistence penetration method)

- ▣ 접촉 발생시 접촉 node수에 비례하는 강성 증가 효과를 제거 하기 위한 수치적 방법
- ▣ Faceting 의 특성에 따라 해석결과가 달라지는 것을 방지



- ▣ 접촉점의 개수에 반비례하도록 k의 값을 수정하여 사용

$$k' = k / n \quad (n : \text{contact point number})$$

$$F = k'\delta + k'\delta \quad F = k'\delta + k'\delta + k'\delta \quad F = k'\delta + k'\delta + k'\delta + k'\delta + k'\delta$$

$$\delta = \frac{F}{k} \quad = \quad \delta = \frac{F}{k} \quad = \quad \delta = \frac{F}{k}$$

Consistence Penetration Method

# Contact Entities- General 3D Contacts



Solid

- Solid Contact Event를 이용
- Rigid – Rigid
- 침투량(Penetration)작고, 곡률반경이 큰 형상에서 좋음



Geo Sur



Geo Sph



Geo Cyl

- Point Contact Event와 Edge Contact Event를 이용
- Rigid – Rigid, Rigid – FE, FE – FE
- 일반적인 형상에 대해 가장 좋은 해석 성능을 나타냄
- Geo Sph와 Geo Cyl의 경우 Analytical Contact의 기능 사용
- CPM(constistence penetration method 및 Smooth patch 기능 사용가능



Sur-Sur



ESUR-Sur



Sph-Sur



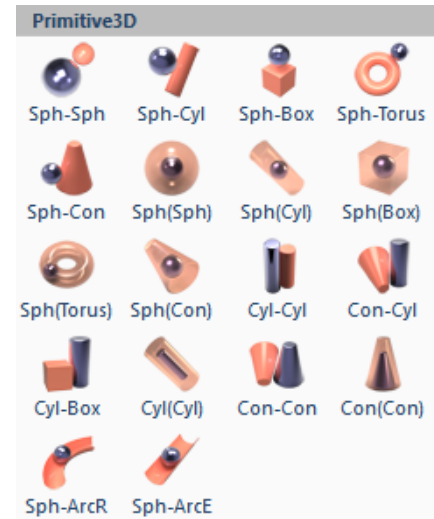
Cyl-Sur

- Geo contact개발 이전의 Point Contact Event만 적용된 Entity
- Rigid – Rigid
- 접촉점에서 contact force display가 표현되지 않음

General Geometry Contact에 있어서 Geo Contact또는 Solid Contact을 사용하는 것이 바람직함

# Contact Entities- Primitive 3D Contacts & 2D Contacts

- **Analytical Contact Event**를 사용
- Rigid – Rigid
- **RecurDyn Geometry** 만 사용가능
- 빠른 해석속도
- Parametric Value를 이용한 Geometry Size연결 및 수정가능



- Point Contact Event와 Edge Contact Event를 이용
- 2D Curve(Ployline, Spline, Circle, Arc, Edge Curve)를 사용
- **Rigid – Rigid, Rigid – FE, FE - FE**



- Point Contact Event만 사용
- 2D Curve(Ployline, Spline, Circle, Arc, Edge Curve)를 사용
- Rigid – Rigid



- **Analytical Contact Event**를 사용
- Rigid – Rigid
- Circle 또는 Edge Curve 및 Outline을 이용하여 모델링



# 합리적 접촉 모델링 과정

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# 합리적 접촉 모델링 과정 개요

Step1

Geometry 및 접촉 형태에 따른 Contact Entity 선택

Step2

Base & Action Geometry의 선택

Step3

Contact Surface의 생성 및 Contact 생성

Step4

Contact Event에 따른 Faceting 정보 수정

Step5

Contact Parameter 입력

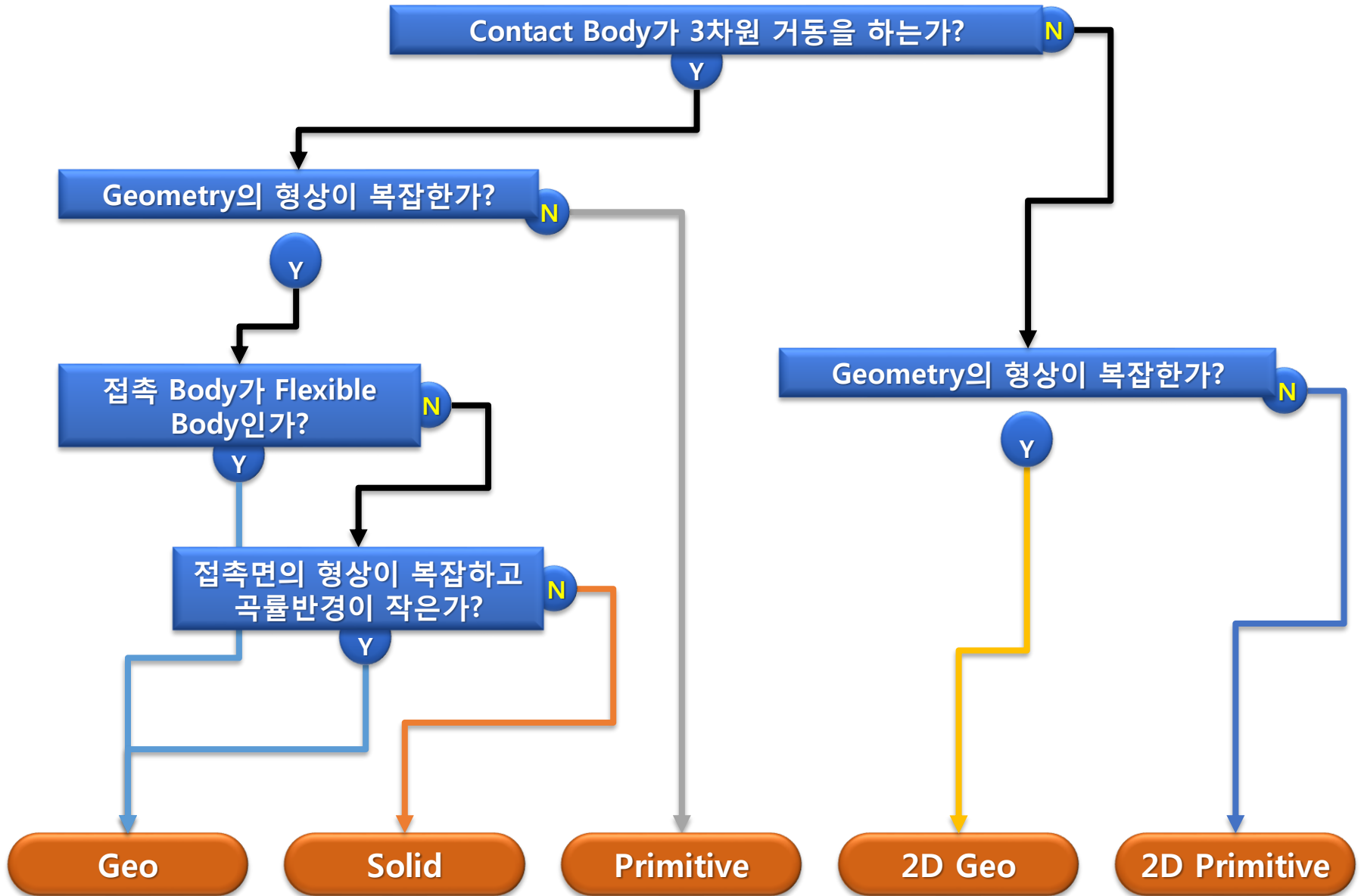
Step6

기타 옵션 설정

Step7

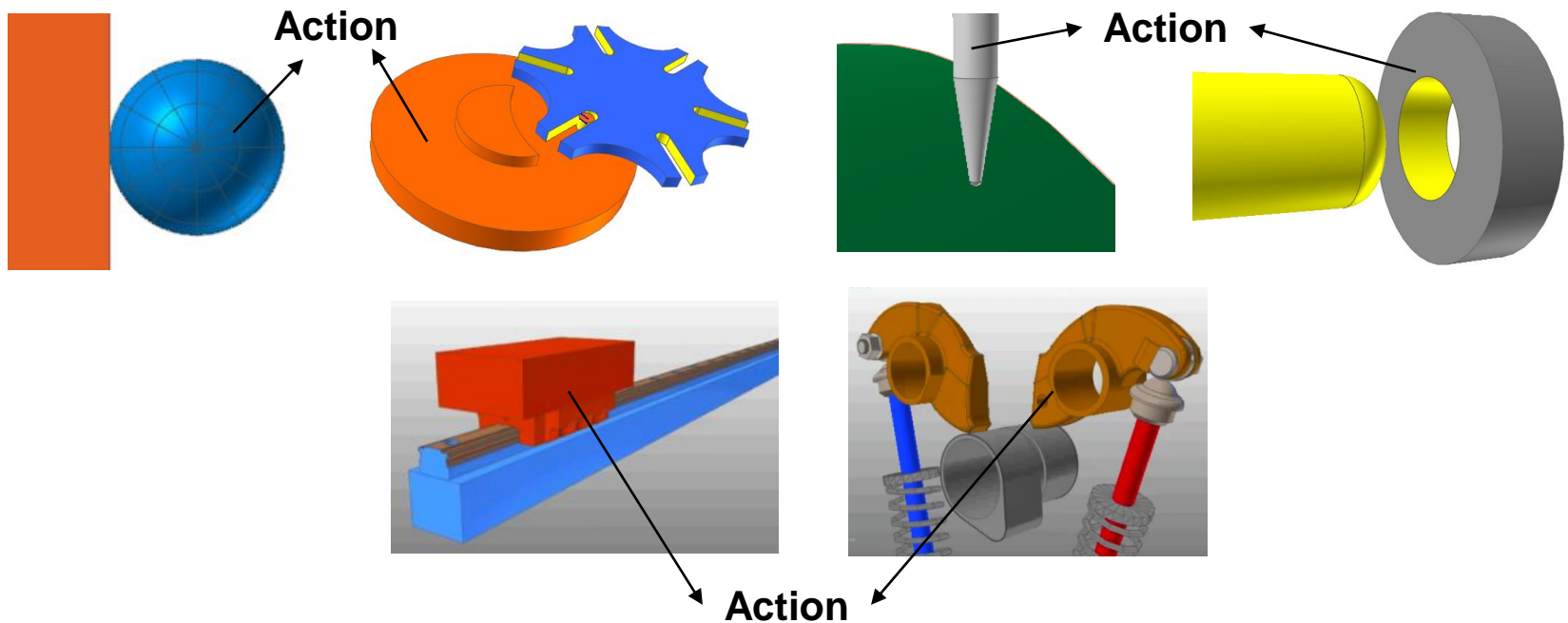
Simulation 수행 및 보정

# Step1 Geometry 및 접촉 형태에 따른 Contact Entity 선택



## Step2 Base & Action Geometry의 선택

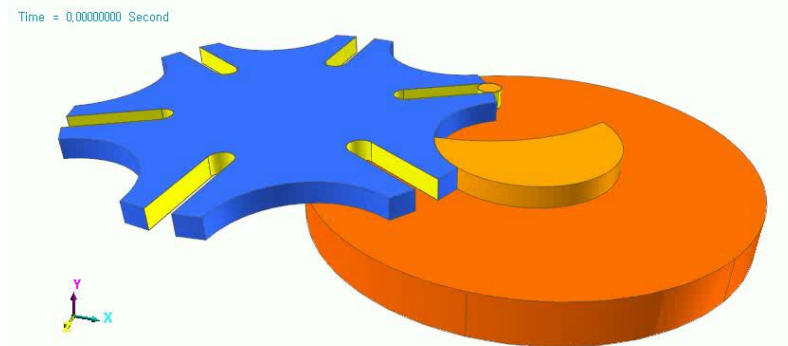
- 접촉면적이 작은 Geometry → Action으로
  - ▣ 접촉면적이 작은 쪽을 Geometry를 조밀하게 Faceting하여 부드러운 접촉 상황 발생에 유리
- 곡률반경이 작은 Geometry → Action으로
  - ▣ 큰 곡률의 Patch의 연결점을 지날 때, 접촉력의 불균일성이 작아짐
- 움직임이 큰 Body의 Geometry → Action으로
  - ▣ Action Body에 대한 계산의 효율성이 더 높게 프로그래밍되어 있음



# Step3 Contact Surface의 생성 및 Contact 생성

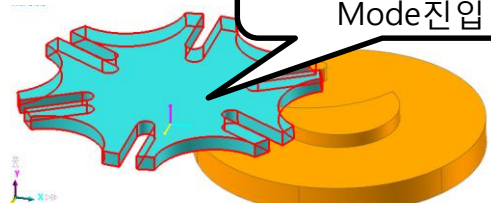
- General Contact은 모두 Solid 또는 Surface를 지정할 수 있지만, 접촉이 발생하는 특정 Surface만 접촉으로 지정하는 것은 Solver의 부담을 크게 줄여줌

## Surface 생성과정

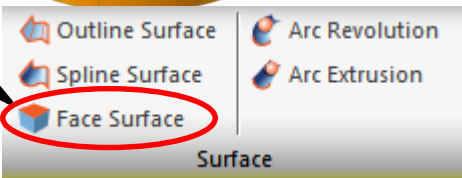


접촉 surface만 사용시 3배 이상 빠른 계산 가능

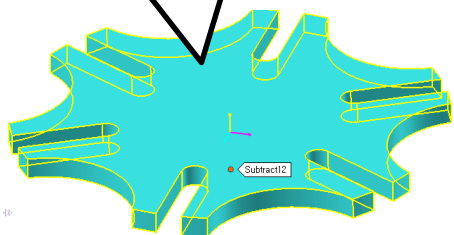
(1) 더블클릭하여 Body Edit Mode진입



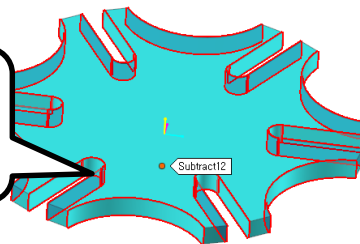
(2) Face Surface 클릭



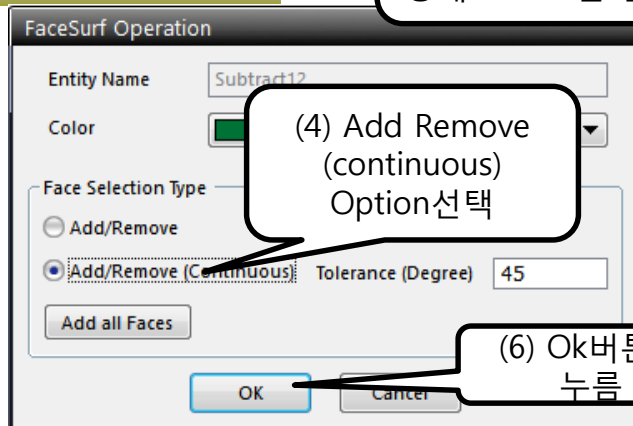
(3) 접촉 Solid선택



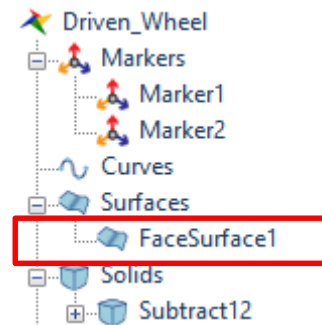
(5) 화면에서 Shift버튼을 누른 상태로 Face를 선택



(4) Add Remove (continuous) Option선택



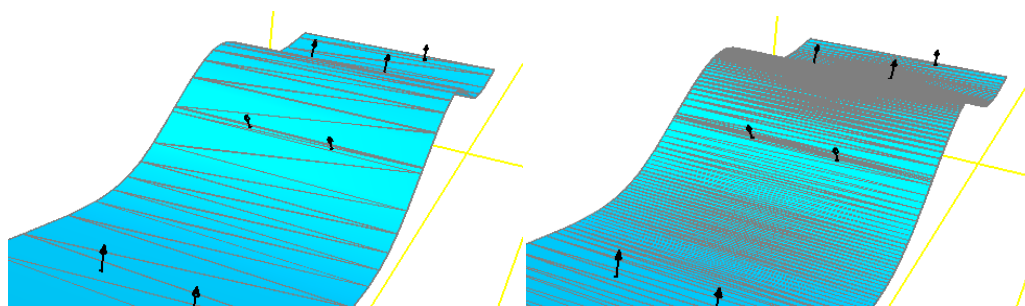
(6) Ok버튼을 누름



# Step4 Contact Event에 따른 Faceting 정보 수정

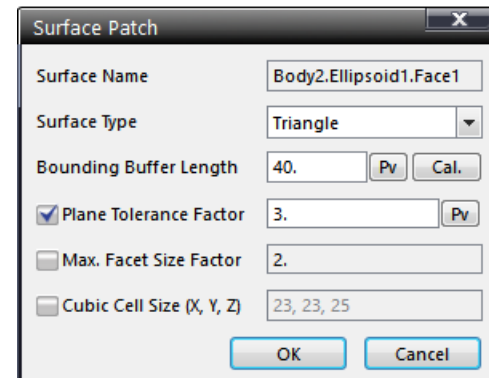
- Geo contact 및 Solid Contact의 경우 Faceting에 따른 해석의 정확도와 계산시간에 민감한 변화를 가져옴

- ▣ Point가 접촉하는 Base Patch의 크기는 곡률을 충분히 나타낼 수 있도록 조밀하게 사용



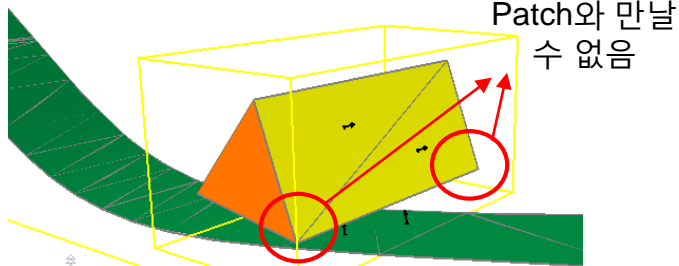
Plane Tolerance Factor: 3.0

Plane Tolerance Factor: 0.2

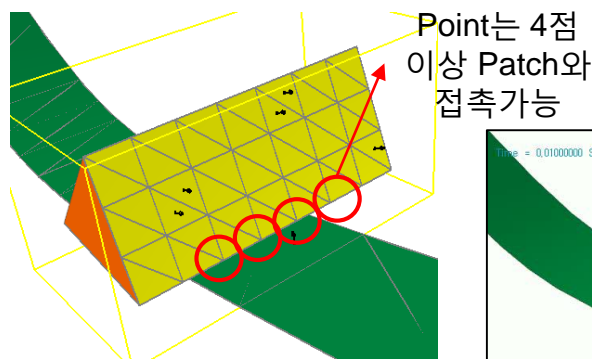


Default value of Faceting control

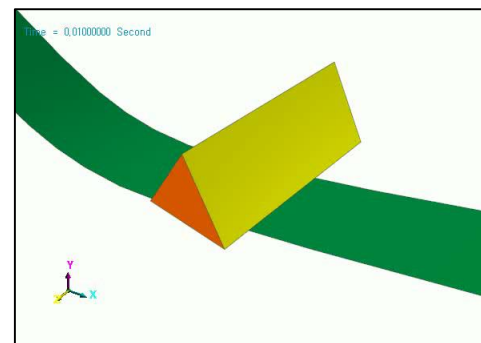
- ▣ 접촉 Point(node)가 존재하는 Action Patch는 접촉상황이 발생할 수 있도록 Facet Size를 조절



Max. Facet Size Factor: 10.0



Max. Facet Size Factor: 2.0



# Step5 Contact Parameter 입력

Properties of GeoSurContact1 [ Current Unit : N/kg/mm/s/deg ]

General Characteristic Geo Contact

Type: Standard Contact Force

Characteristic

Spring Coefficient: 100000. Pv

Damping Coefficient: 10. Pv

Dynamic Friction Coefficient: 0. Pv Friction

Stiffness Exponent: 2. Pv

Indentation Exponent

Boundary Penetration

Boundary Penetration: 1.e-002 Pv

Rebound Damping Factor: 0.25 Pv

Maximum Penetration: 0.8 Pv

Maximum Stepsize Factor: 2. Pv

Scope OK Cancel Apply

Hertz Contact Theory로 부터 계산식을 이용하여 K값 결정(Tuning Point)

$$K = \sqrt{\frac{16RE^2}{9}}$$

$$\left\{ \begin{array}{l} R = \frac{R_1 R_2}{R_1 + R_2} \\ E = \frac{E_1 E_2}{E_2(1-\nu_1^2) + E_1(1-\nu_2^2)} \end{array} \right.$$

Damping Coefficient 입력: 보편적으로 Stiffness의 1/10000정도 사용(Tuning Point)

Friction Definition

Static Threshold Velocity: 1. Pv

Dynamic Threshold Velocity: 1.5 Pv

Static Friction Coefficient: 0. Pv

Maximum Friction Force: 0. Pv

Close

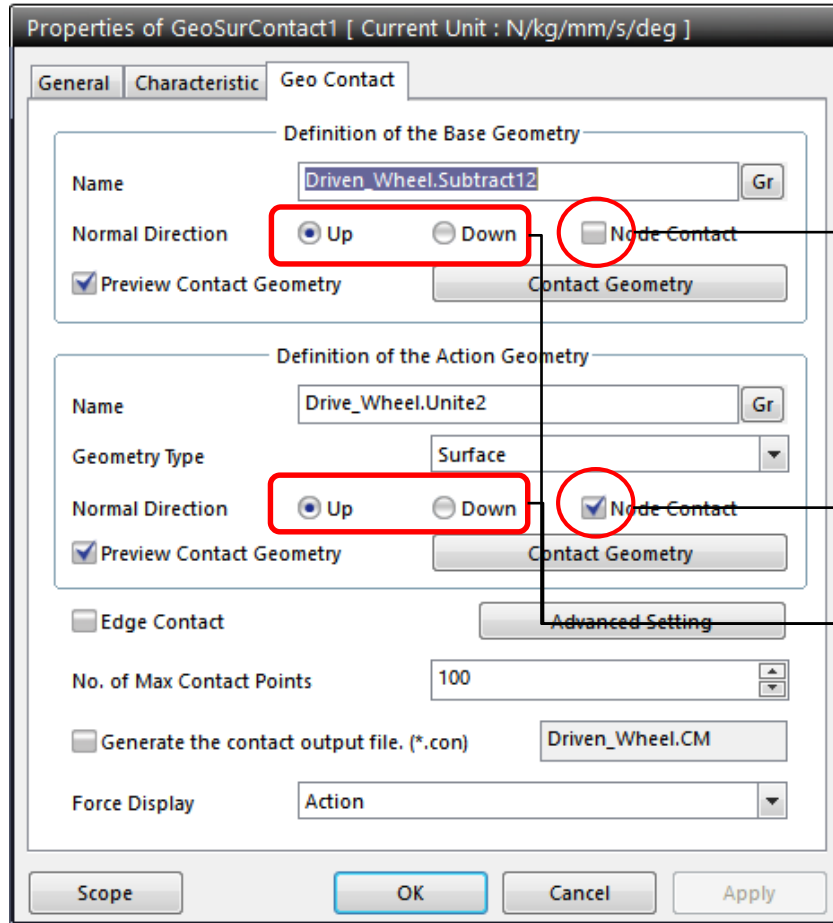
Friction Coefficient 입력 정마찰 및 동마찰 계수는 실험이나 논문의 결과를 참조하여 입력 Threshold Velocity는 default로 사용

Stiffness Exponent는 Hertz Contact 이론에 따라 1.5로 사용(Tuning Point)

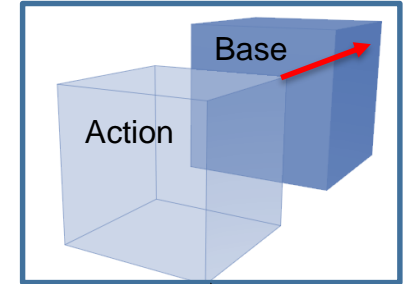
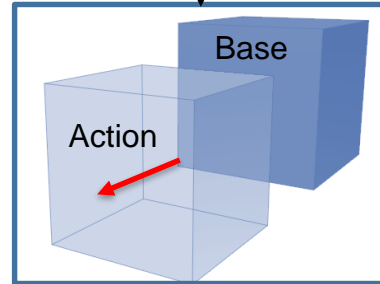
Maximum Penetration값은 접촉해제를 피하기 위해 1mm사용(해석상황에 따라 보고 보정)

원거리에서 접근하는 상황일 경우 10.0 사용 계속 붙어서 움직이는 접촉일 경우 1.0 사용 ★

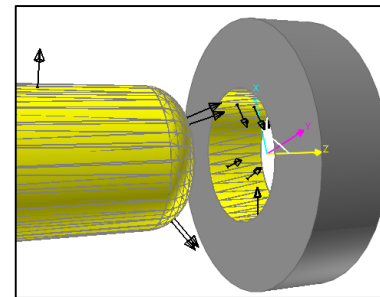
# Step6 기타 옵션 설정



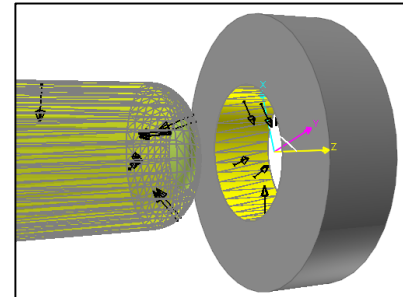
**Node Contact** 옵션은 각 Geometry의 Point(Node)가 상대 Patch에 Contact Event를 발생시킬 것인지 결정하는 것으로 가급적 **Action Geometry의 Node Contact 만 Check**



**Normal Direction Check**  
Geometry의 Surface의 경우 접촉이 발생하는 방향벡터의 설정이 필요하며, Working Windows의 벡터 Icon을 통해 가시적으로 확인하면서 수정



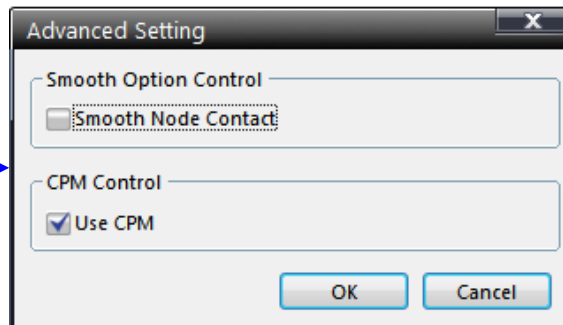
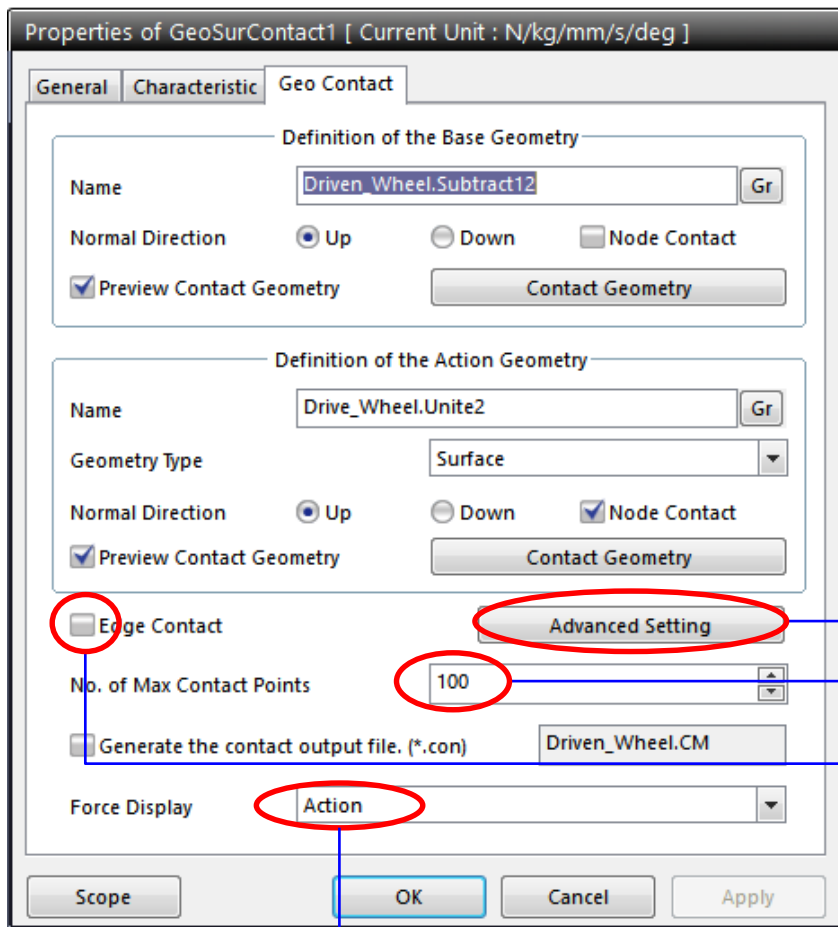
Base: up Action: up  
Good!



Base: up Action: down  
Wrong!



# Step6 기타 옵션 설정



**Smooth Option을 사용해야 할 경우 (가급적 Off)**

- 중공형 Cylinder에 Shaft를 끼워 넣는 Contact
- 넓은 곡면을 소수의 접촉점이 지나가는 경우
- 곡률이 큰 곡면을 매끄럽게 미끄러져야 하는 경우

**CPM Option을 꺼야 할 경우 (가급적 On)**

- 중공형 Cylinder에 Shaft를 끼워 넣는 Contact
- 복잡한 형상의 Geometry 접촉 시 접촉위치가 다양하고 Normal Vector 각각 다른 경우

**Edge Contact을 켜야 할 경우(가급적 Off)**

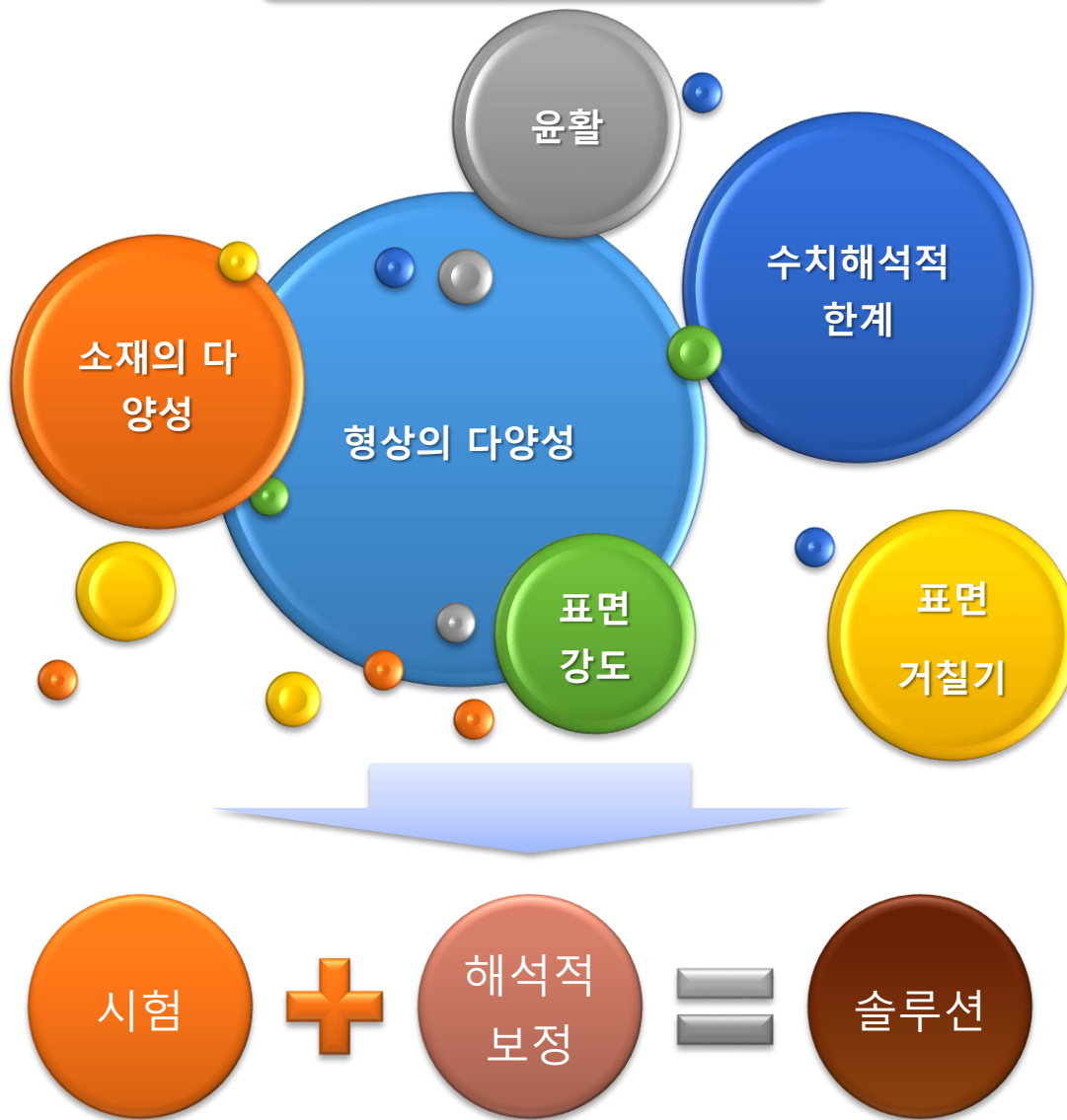
- Geometry의 모서리만 접촉이 발생할 경우

**No. of Max Contact Points :** 이 파라미터는 Display Point의 개수를 의미하므로 해석결과에 영향을 주지 않는다. 100정도 사용하면 무난함

**Force Display:** 주로 Action만 켜서 확인

# Step7 Simulation 수행 및 보정

## 접촉모델의 불확실성



# Step7 Simulation 수행 및 보정

- 해석수행 및 해석 결과와 해석 속도를 검토하여 각종 Parameter를 보정한다.
  - ▣ Check Point 1: **정상적 Contact 상황** 발생유무
    - Contact이 통과하거나 비정상 위치에서 접촉이 발생 하지 않을 경우
      - ✓ Geometry간의 간격 확인 및 Facet Size 조밀하게 수정
      - ✓ Maximum Penetration값 증가
      - ✓ Normal Vector 방향 확인
  - ▣ Check Point 2: **침투량(Penetration)**
    - 침투량이 지나치게 크거나 접촉상황이 발생하지 않고 통과할 경우
      - ✓ Stiffness coefficient 증가
      - ✓ Exponent 증가
      - ✓ CPM(consistence penetration method) off
    - 침투량 자체가 중요한 해석의 경우(MTT)
      - ✓ 하중을 미리 계산하여 침투량을 충족 시키는 Stiffness의 값을 계산하여 적용
  - ▣ Check Point 3: **반발특성**
    - 반발특성이 거의 발생하지 않거나 너무 많이 튀는 경우
      - ✓ Stiffness coefficient 조절
      - ✓ Exponent 조절
      - ✓ Damping coefficient 조절(**조금씩 변화하며 확인**)
    - 실험에 의한 대수감쇠율을 알고 있을 경우
      - ✓ 반복적 해석을 통해 충족하는 Damping Coefficient값을 찾아야 함

# Step7 Simulation 수행 및 보정

## Check Point 4: Solving Step Size

- 접촉 해석상황이 지나치게 많은 해석시간을 소요할 경우 특히, Step Size가 매우 작아지는 경우
  - ✓ 반발특성과 침투량이 적절한 응답을 나타내는 범위에서 Stiffness 감소
  - ✓ 반발특성과 침투량이 적절한 응답을 나타내는 범위에서 Exponent 증가
  - ✓ 반발특성과 침투량이 적절한 응답을 나타내는 범위에서 Damping coefficient 조절
  - ✓ Contact모델이 있는 경우 Solver Option의 Maximum Step Size는 0.001이하의 값을 사용

## Check Point 5: Contact Force의 선형성

- 두 Geometry가 서로 붙은 상태에서 이동하여 접촉위치가 지속적으로 변할 때 접촉하중이 불균일하게 나타나는 경우
  - ✓ Facet size 조밀하게 조정
  - ✓ Smooth contact 적용
  - ✓ Stiffness 감소 와 Exponent 증가를 동시에 진행하여 접촉 진동감소

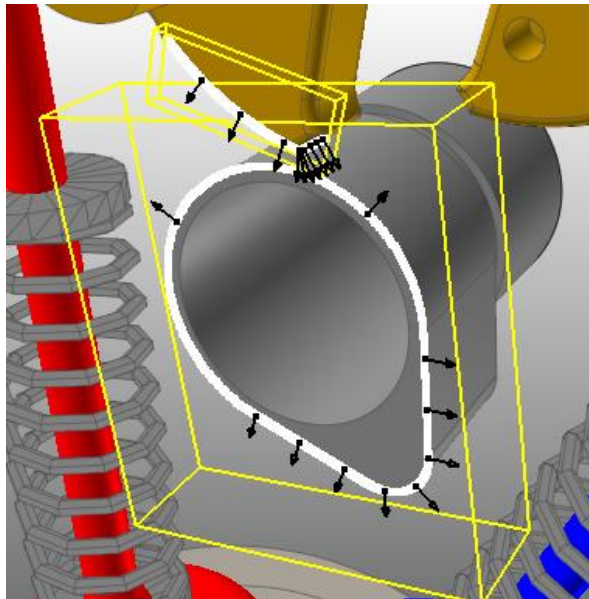
# Case study

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## ● 모델 설명

☐ Cam Body, Rocker Body 및 Valve가 서로 접촉하면서 메커니즘을 만들어냄

- 총 4개의 GeoCurveContact사용
- 2D GeoCurveContact 사용
- CPM, Smooth 사용
- Curve Segment 200개 사용
- K:100000 C:10 Exp:1.5 Fric:0.1



Cam to Rocker

Curve Name: C1\_ImportedCurve1  
Curve Type: Line  
Curve Segment: 200  
 Use Total Segment  
Bounding Buffer Length: 6. [Pv] dCurve1 [Gr]  
 Cubic Cell Size (X, Y, Z): 54, 52, 1 [Dir]  
Normal Direction:  Up  Down  Node Contact  
 Preview Contact Geometry [Contact Geometry]

Definition of the Action Geometry  
Name: Rocker\_L.C1\_ImportedCurve1 [Gr]  
Contact Plane Normal: -1., 0, 0 [Dir]  
Normal Direction:  Up  Down  Node Contact  
 Preview Contact Geometry [Contact Geometry]

Advanced Setting

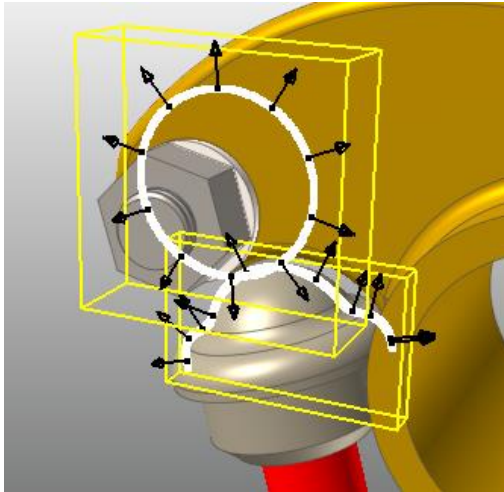
No. of Max Contact Points: 10

Generate the contact output file. (\*.con) [Rocker\_L.CM]

Force Display: Action

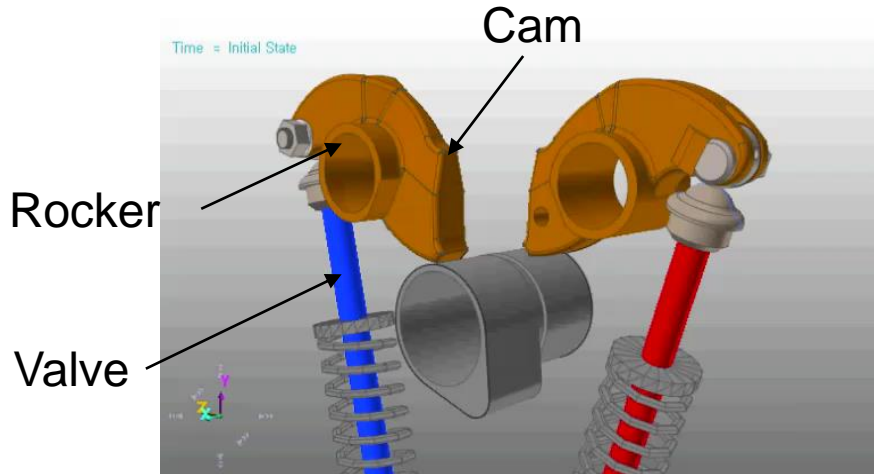
GeoCurve Dbox

# Cam System



Cam to Rocker

- Animation and Plot



Cam working animation

Type: Standard Contact Force

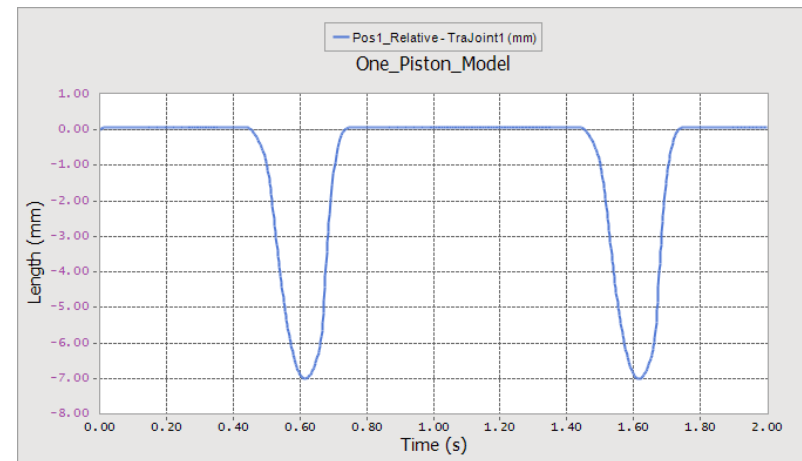
Characteristic

Spring Coefficient	100000.	Pv
Damping Coefficient	10.	Pv
Dynamic Friction Coefficient	0.1	Pv Friction
<input checked="" type="checkbox"/> Stiffness Exponent	1.5	Pv
<input type="checkbox"/> Indentation Exponent	<input checked="" type="radio"/> Boundary Penetration	
Boundary Penetration	1.e-002	Pv
<input checked="" type="checkbox"/> Rebound Damping Factor	0.25	Pv

Maximum Penetration: 1. Pv

Maximum Stepsize Factor: 1. Pv

Characteristic Dbox



Valve displacement

## ● 모델설명

### ■ Ball과 Arc Revolution Geometry의 접촉에 의해 작동

- 총 40개의 SphereToArcRevolution Contact사용
- Face surface추출 및 Faceting 최적화
- K:100000 C:10 Exp:2.0 Fric:0.15

Characteristic

Spring Coefficient	100000.	Pv
Damping Coefficient	10.	Pv
Dynamic Friction Coefficient	0.15	Pv Friction
<input checked="" type="checkbox"/> Stiffness Exponent	2.	Pv
<input type="checkbox"/> Damping Exponent	1.	
<input type="checkbox"/> Indentation Exponent	2.	

Buffer Radius Factor 1.2 Pv

Maximum Stepsize Factor 1. Pv

Characteristic Dbox

Definition of the Base Arc Revolution

Name		Gr
Arc Radius	6.578	
Start Angle of Arc		End Angle of Arc
Arc Center Offset	Vertical 0.	Horizontal
Start Angle of Rev	0.	End Angle of Rev 360.
Open Face	<input checked="" type="checkbox"/> Start Face	<input checked="" type="checkbox"/> End Face
Normal Direction	<input checked="" type="radio"/> Inward	<input type="radio"/> Outward Helix

Definition of the Action Sphere

Name		Gr
Sphere Radius	6.34	

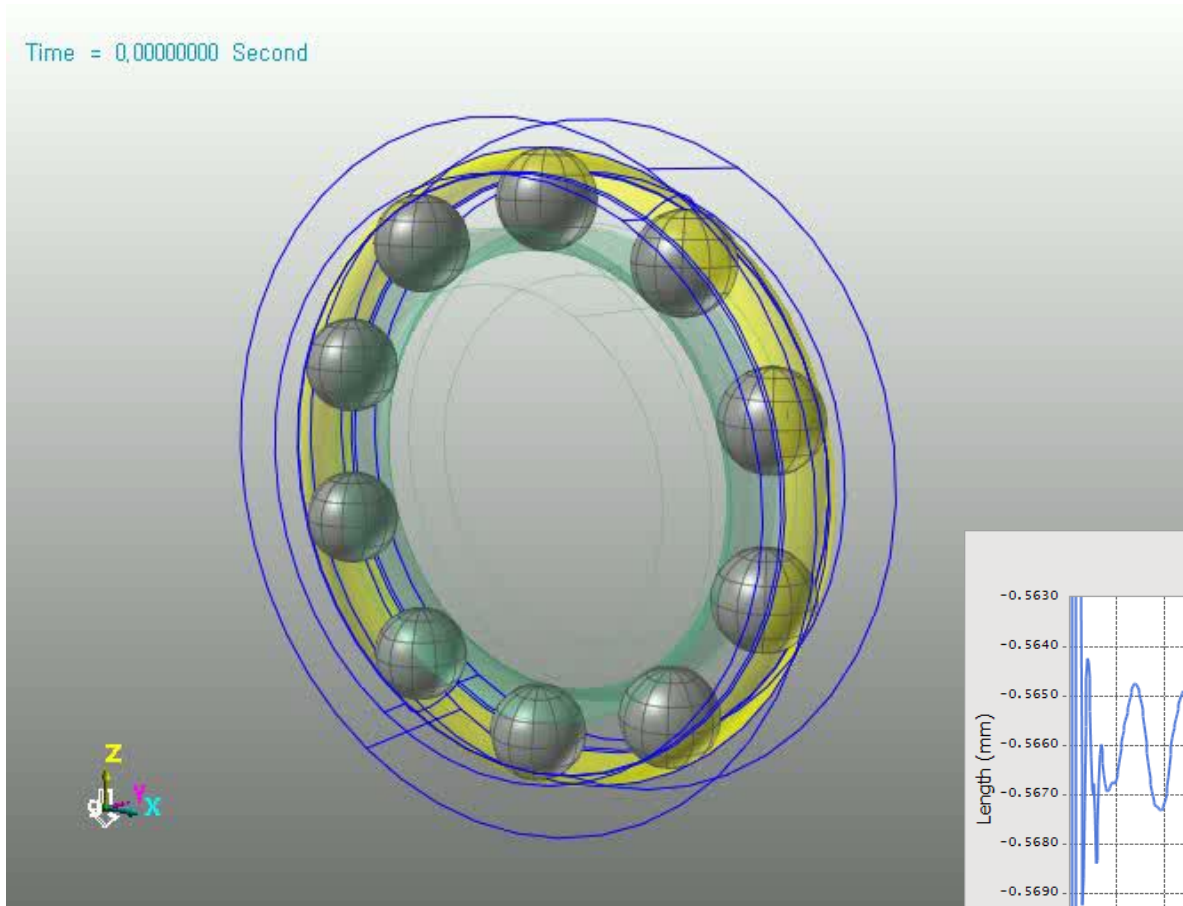
Force Display Action  Synchronize with Geometry

SphereToArcRevolution Dbox

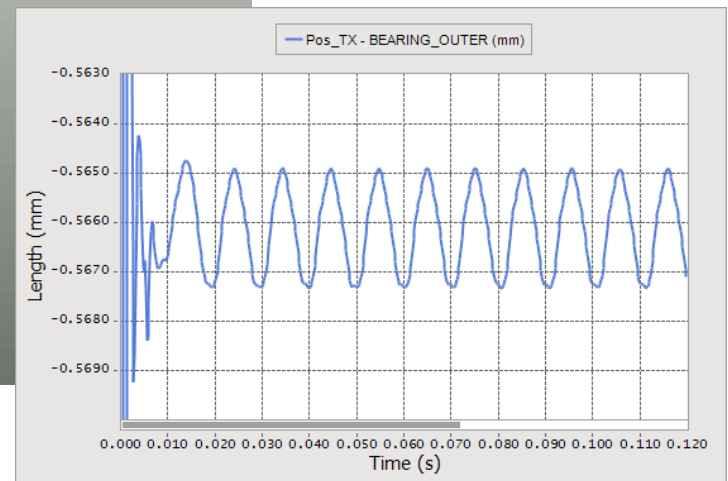


# Ball Bearing

- Animation and Plot



Ball bearing animation



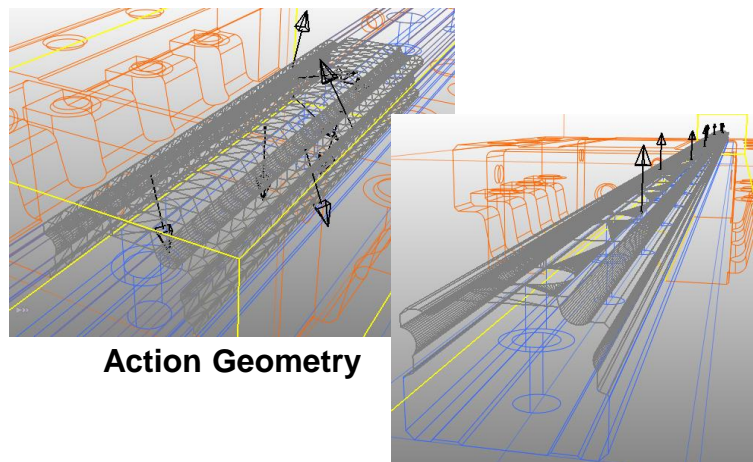
Outer ring vertical displacement

## ● 모델 설명

■ Steel Rail위를 LM Guide가 면접촉을 하며 직선운동을 하는 메커니즘

- 1개의 GeoSurface Contact사용
- Face surface추출 및 Faceting 최적화
- CPM 사용안함
- K:1000 C:0.1 Exp:2.0 Fric:0.1
- Faceting을 최적화
  - ✓ Base:PTF0.1(단면형상 곡면표현), MFSF10
  - ✓ Action:PTF0.5, MFSF0.5(접촉node증가)

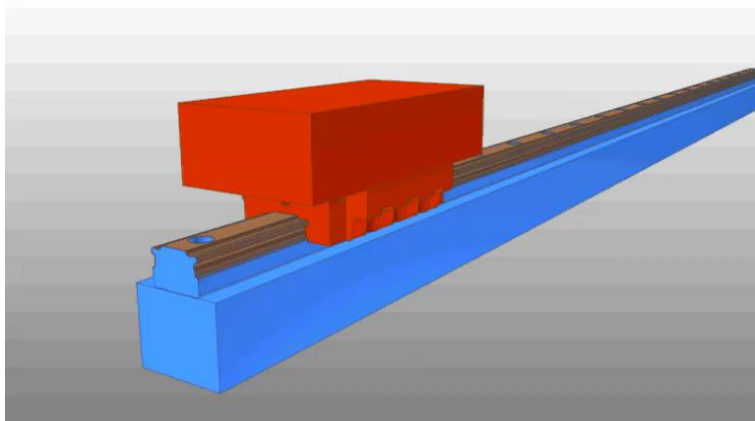
MFSF : Max. Facet Size factor



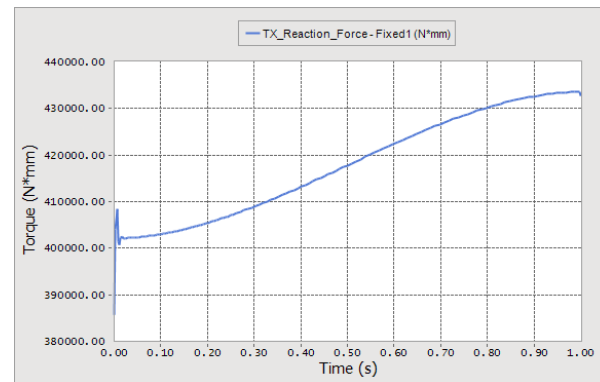
Action Geometry

Base Geometry

## ● Animation and Plot



LM guide animation

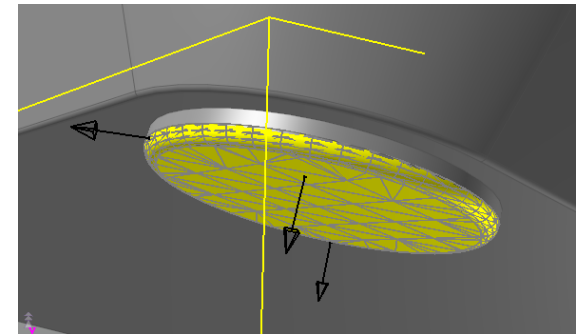


Hinge point reaction torque

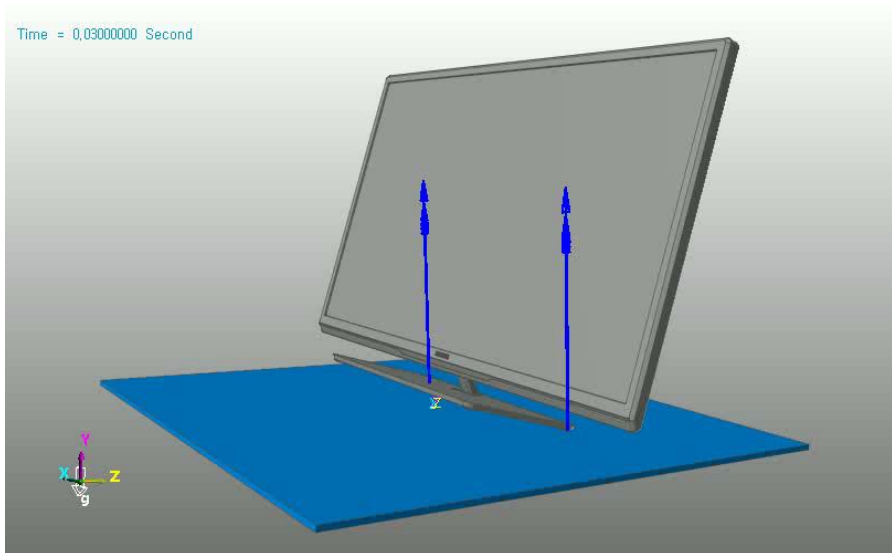
## ● 모델설명

▣ 접촉에 의해 자세를 유지하는 제품에 자세 안정성을 검토하는 해석

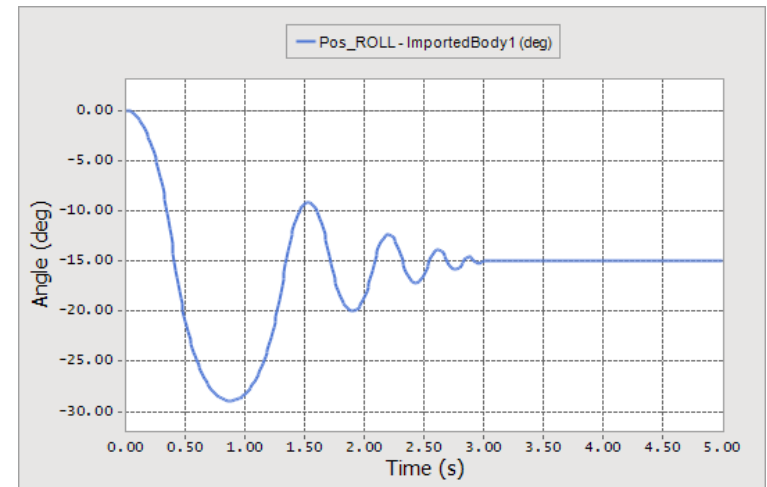
- 1개의 GeoSurface Contact사용
- Face surface추출 및 Faceting 최적화
- CPM 사용
- K:10000 C:100 Exp:2.0 Fric:1.0
- Faceting을 최적화
  - ✓ Action:PTF3.0, MFSF0.1(접촉node증가)
- Max Penetration : 5.0



Action Geometry



Wobble analysis animation

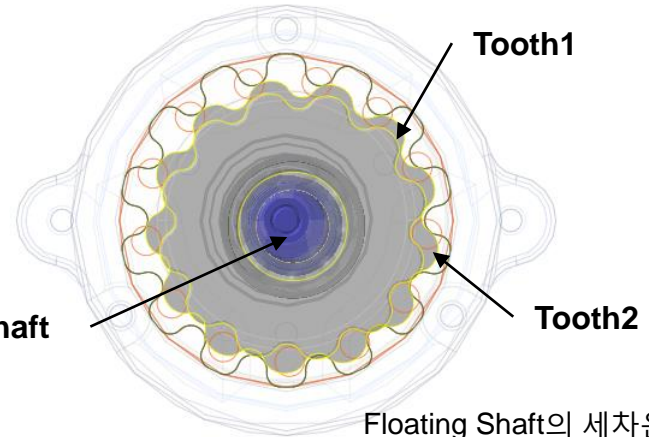


Pitch Angle

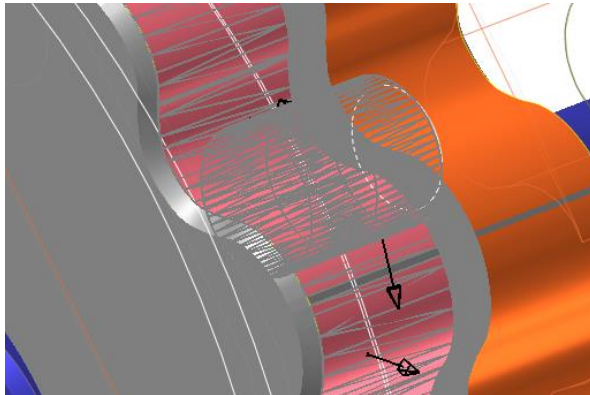
## ● 모델설명

▣ 내측기어의 형태를 2가지로 구성하여 다른 회전 중심으로 회전하며 접촉하여 높은 기어비를 생성하는 감속기, 완전히 접촉에 의한 메커니즘

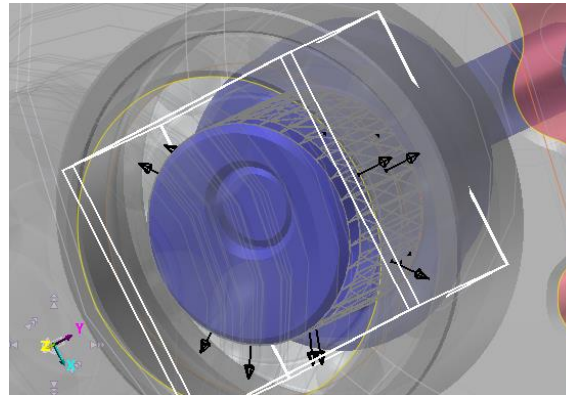
- 3개의 Geo Contact사용
- Face surface추출 및 Faceting 최적화
- CPM 사용안함
- Sliding shaft contact에서 smooth사용
- K:10000 C:1.0 Exp:2.0 Fric:0.01



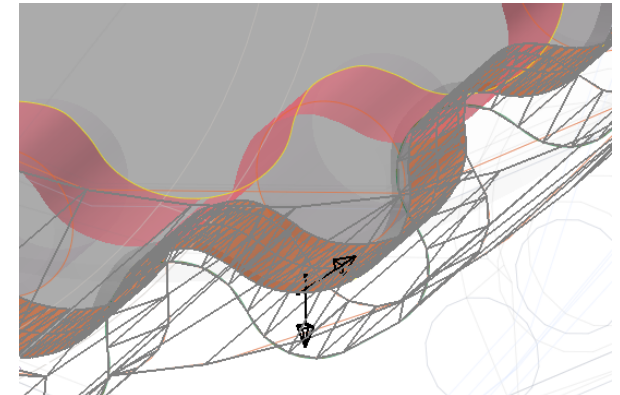
Floating Shaft의 세차운동에 의해 기어비가 만들어짐



Tooth1 Contact



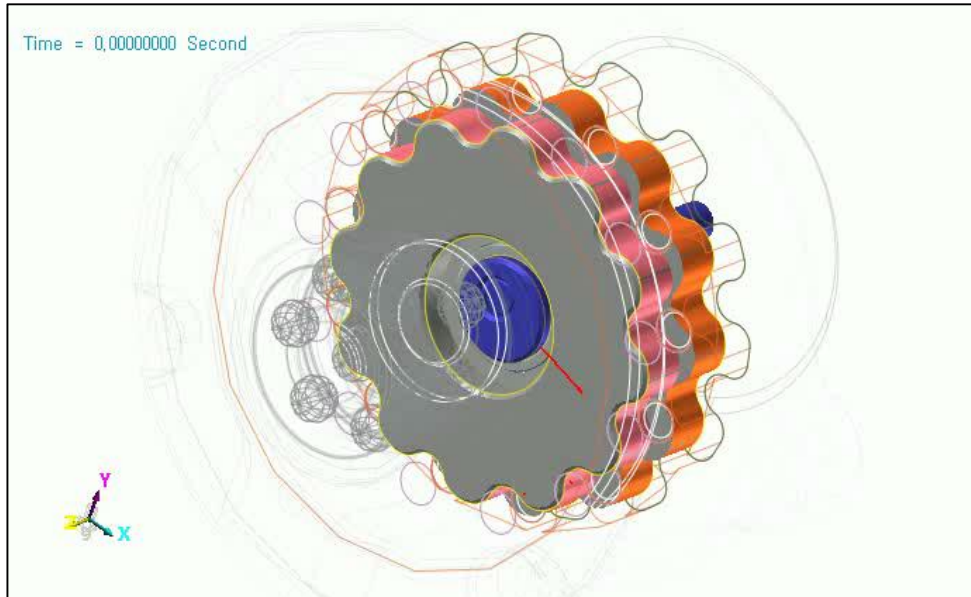
Sliding shaft contact



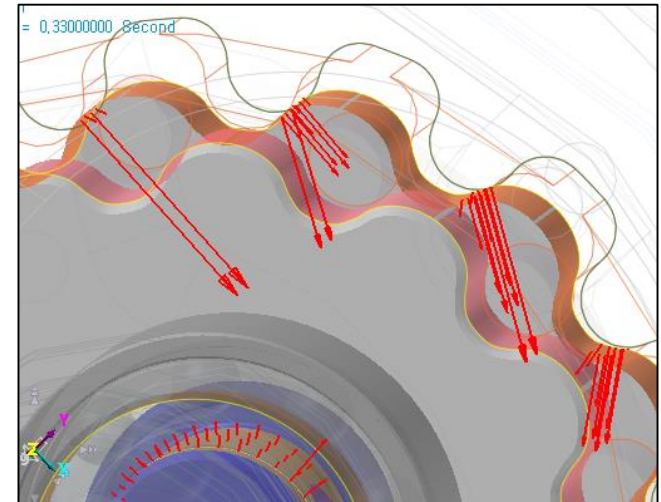
Tooth2 Contact

# Cycloid drive

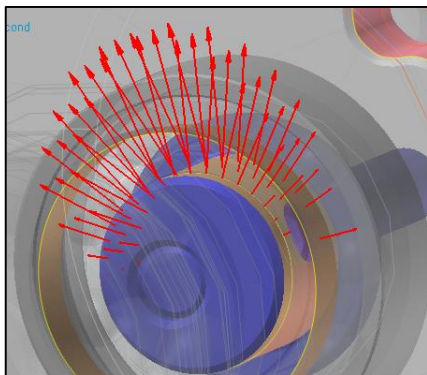
## ● Animation and Plot



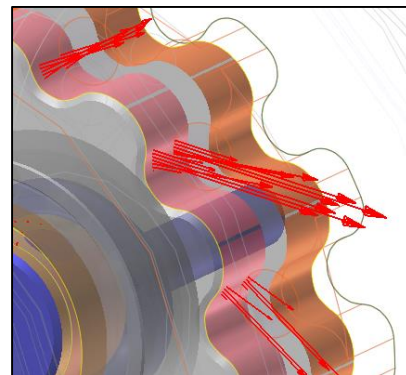
Cycloid Drive Animation



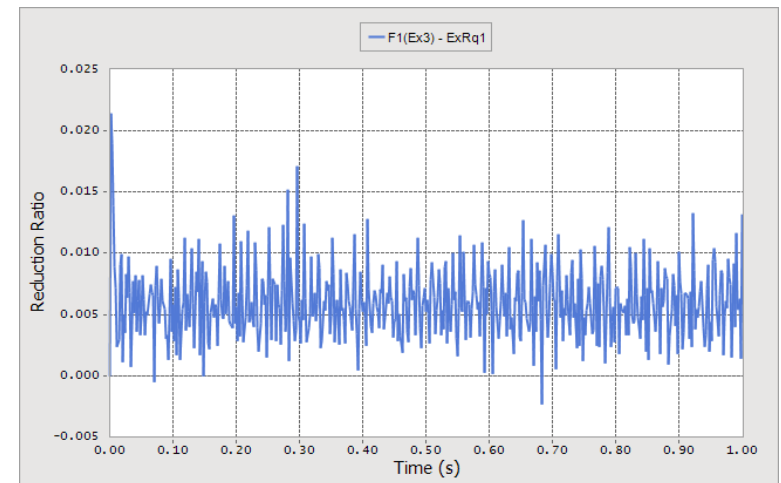
Tooth2 Contact



Sliding shaft contact



Tooth1 Contact



Reduction Ratio

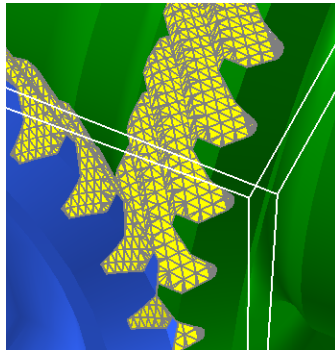
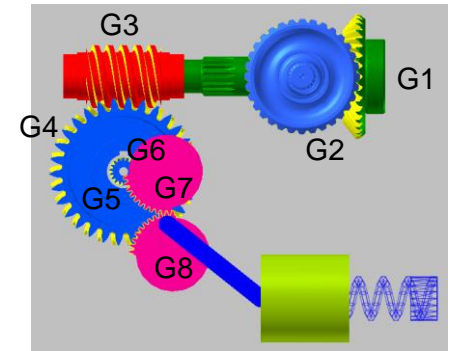
# Gear contact

Sim time: 1sec, CPU time 2m 19sec

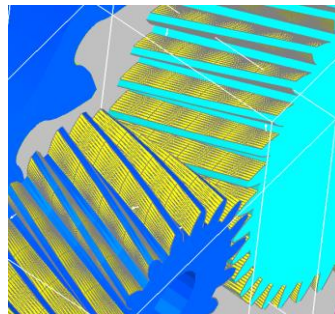
## ● 모델설명

### ▣ 광범위하게 사용되고 있는 기어 시스템의 접촉 모델링

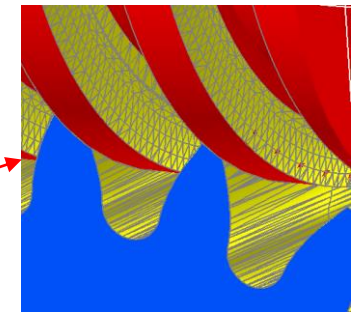
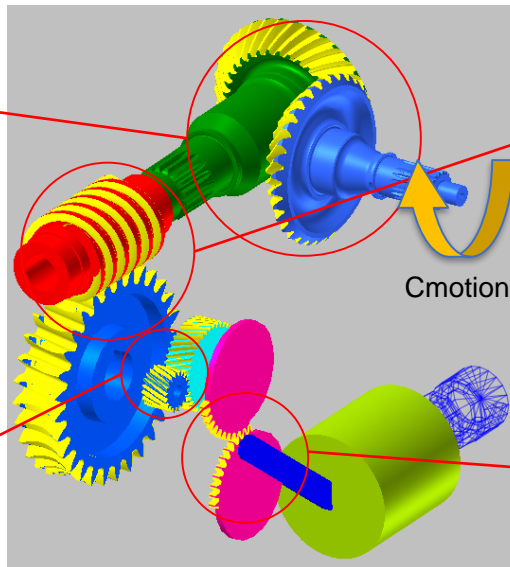
- 5개의 Geo Contact사용
- Face surface추출 및 Faceting 최적화
- CPM 사용
- K:100000 C:10 Exp:2.0 Fric:0.01



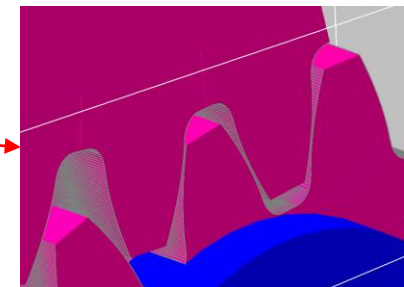
G1-G2 Contact(Bevel)  
PTF1.0, MFSF10



G5-G6 Contact(Helical)  
PTF3.0, MFSF10.0



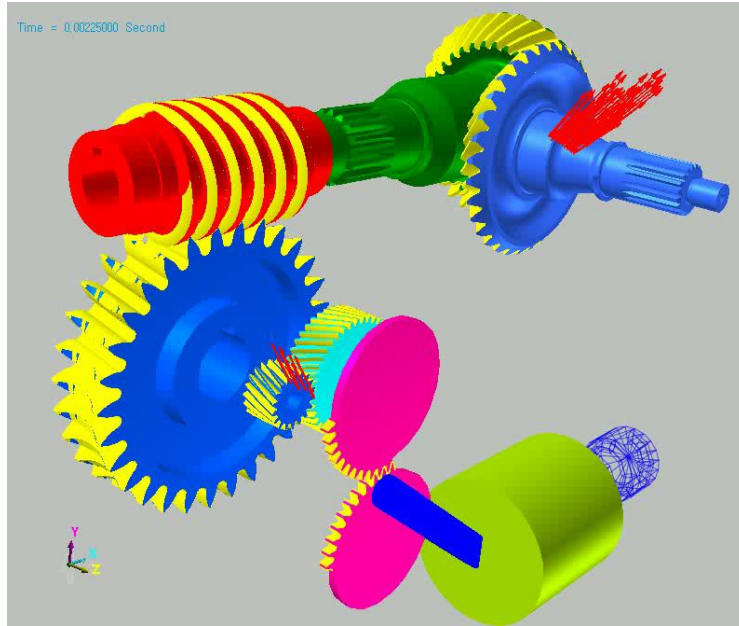
G3-G4 Contact(Worm)  
PTF1.0, MFSF10



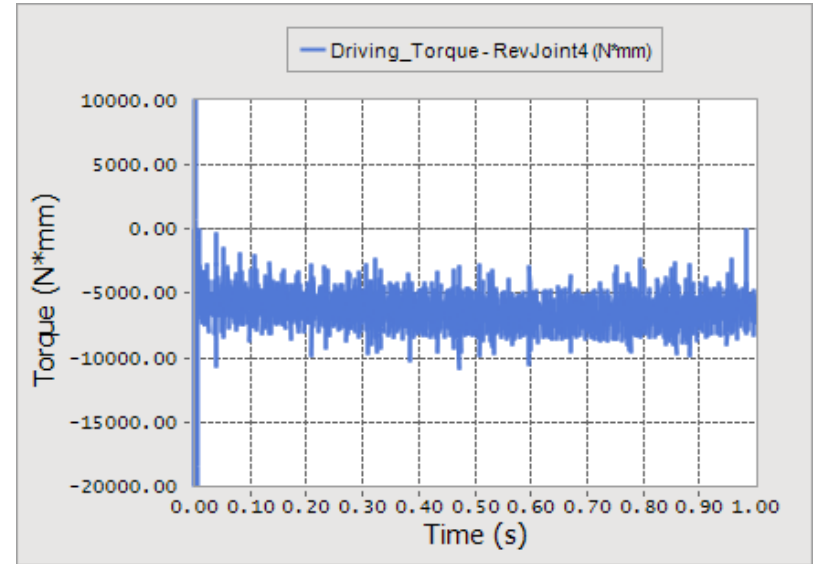
G7-G8 Contact(Spur)  
PTF3.0, MFSF0.5

# Gear contact

- Animation and Plot

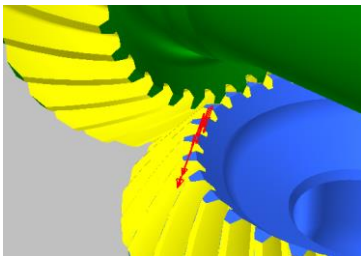


Gear contact animation

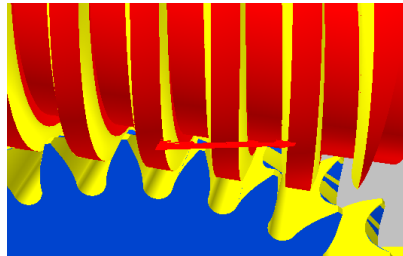


Driving torque variation

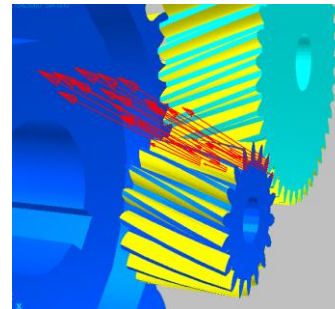
- Contact Shape



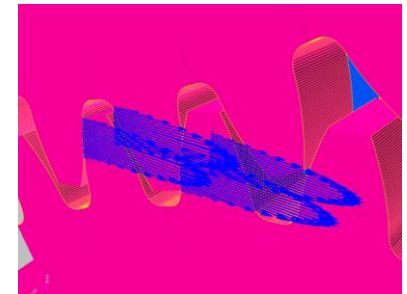
G1-G2 Contact(Bevel)



G3-G4 Contact(Worm)



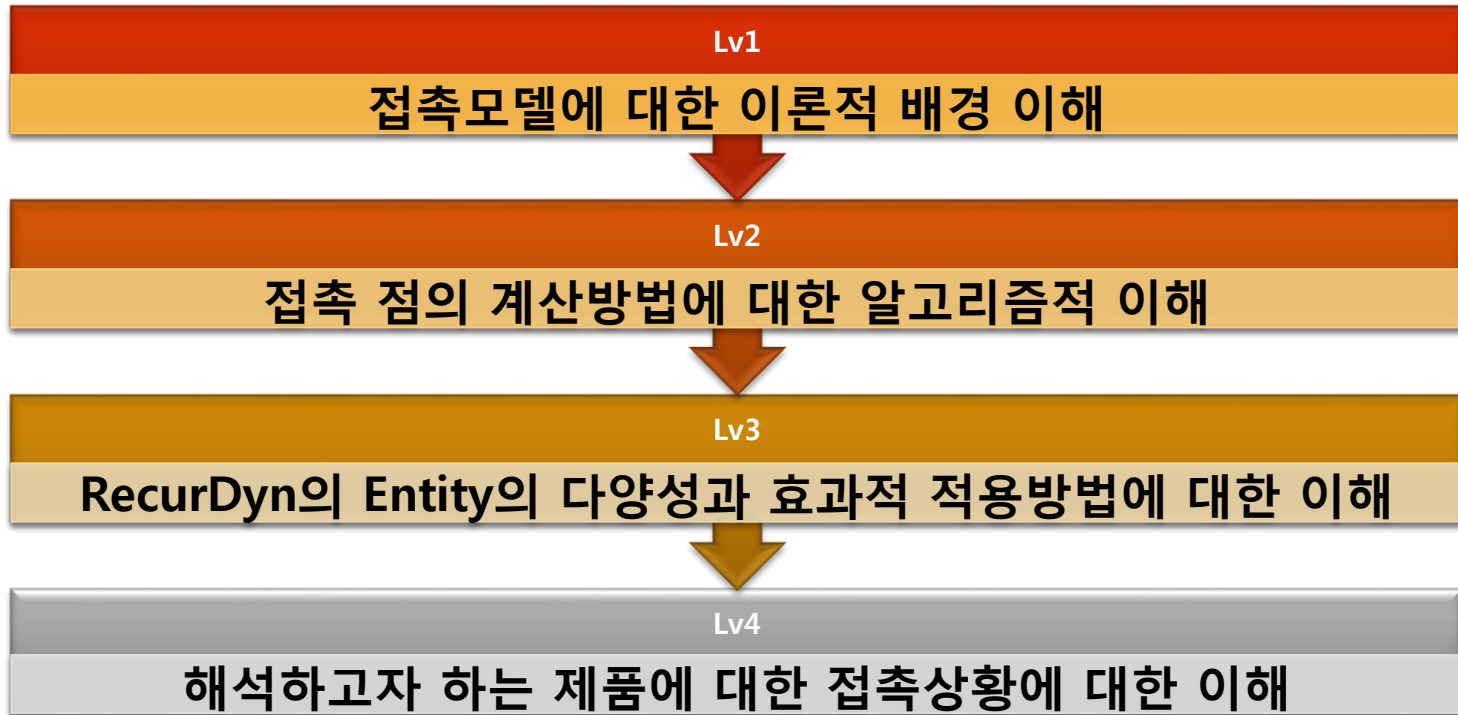
G5-G6 Contact(Helical)



G7-G8 Contact(Spur)

# Conclusion

합리적 방법을 통해 접촉 모델링을 통해 보다 빠르고 정확한 솔루션 획득할 수 있습니다.



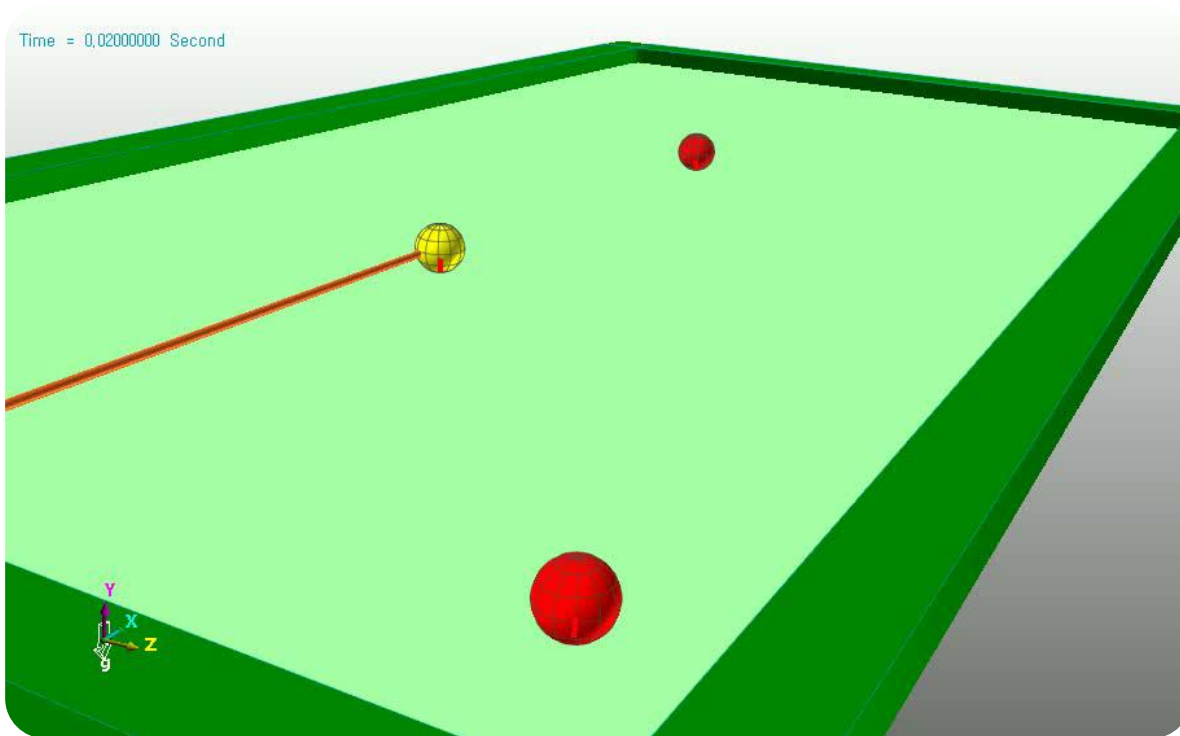


# Conclusion



Contact !

이제 어려워하지 마세요!





# 감사합니다.

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