한국수자원공사 교육 자료(2005. 9. 8)

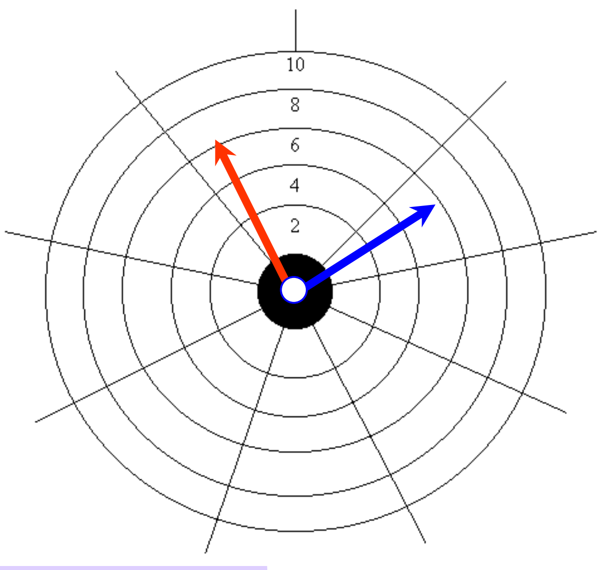
Field Balancing의 절차와 방법

최 성 필 박사
㈜터보링크

Balancing 이란?

ISO 1925

회전체의 질량 분포를 조사하고 필요하다면 저널의 진동과 베어링의 작용력들이 운전속도에 대응하는 주파수에서 특정한 한계 내에 있도록 조정하는 절차

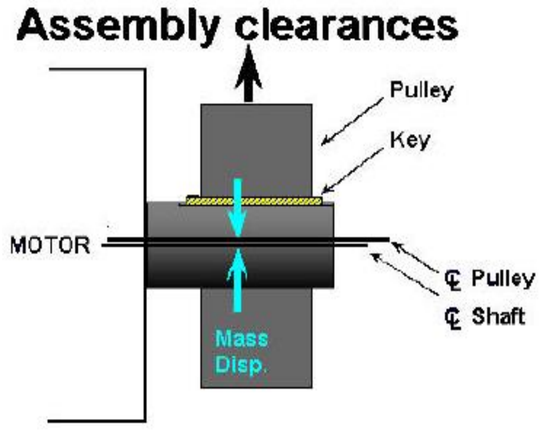


Balancing Machine

- **Balancing**
  - **Shop Balancing**
    - **Low Speed Balancing Machine**
      - **Soft Mount Type**
      - **Hard Mount Type**
    - **High Speed Balancing Machine**
      - **Soft Mount Type**
      - **Hard Mount Type**
  - **Field Balancing**

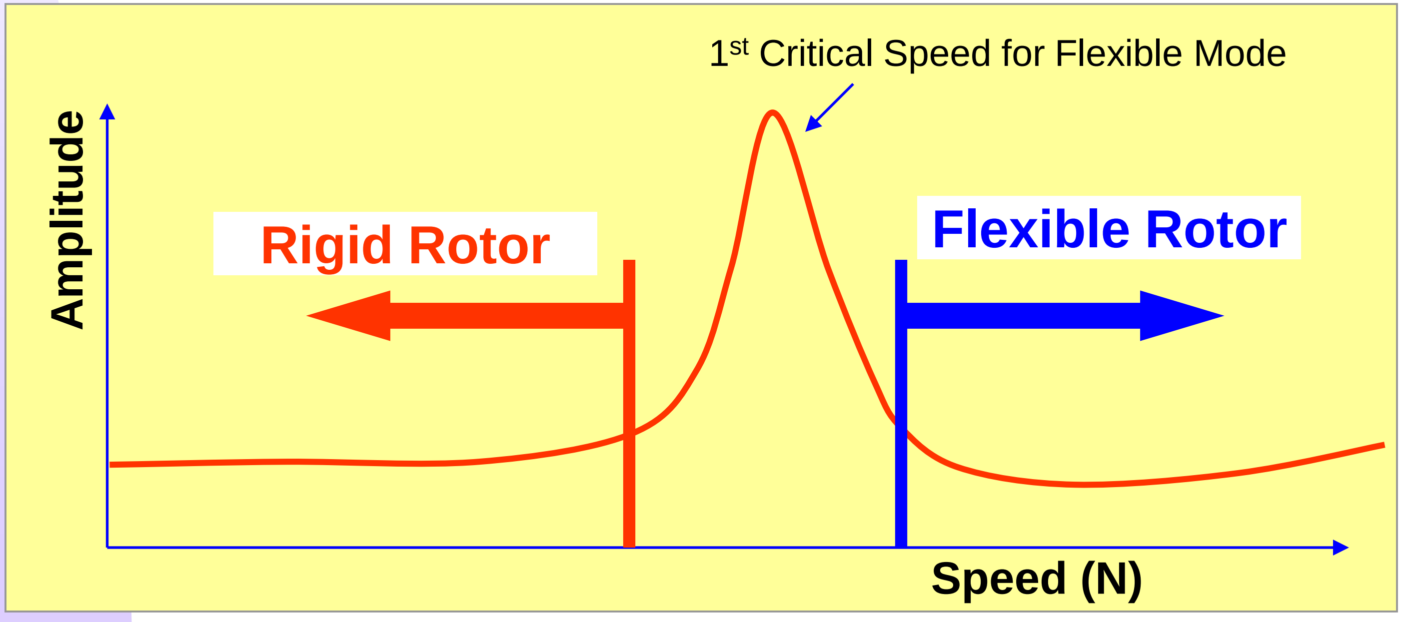
불평형 원인

- **Manufacturing (제작)**
  - 소재 밀도(material density) 의 불균일
  - 가공 정밀도
  - 비대칭 형상
  - Etc.
- **Assembly (조립)**
  - 조립 공차
- **Operation**
  - 부식
  - 이물질 부착



회전체 분류(ISO)

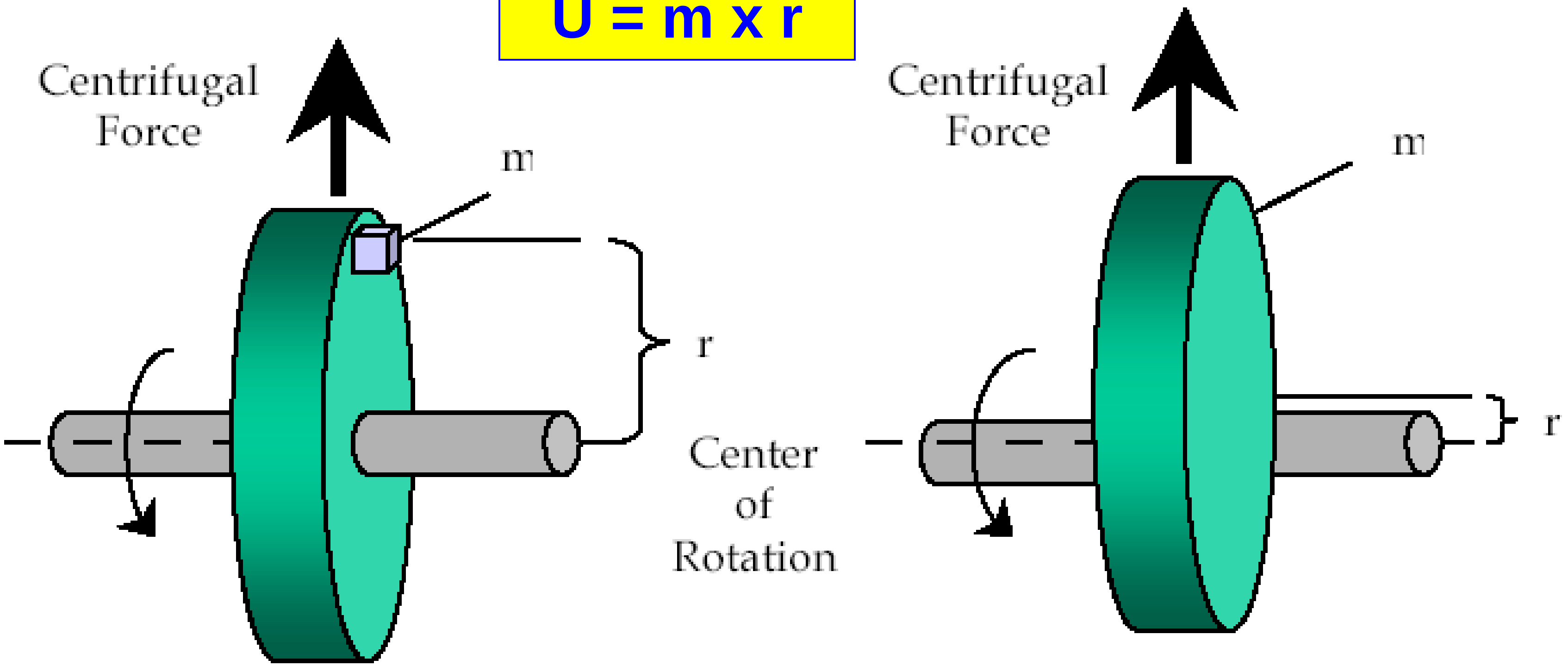
- **Rigid Rotor(강성 회전체)**
  - 양면 밸런싱으로 수정가능한 로터로써, 로터의 최대 운전속도까지 승속하여도 잔류 불평형량이 변하지 않는 로터.
- **Flexible Rotor(탄성 회전체)**
  - Rigid Rotor를 제외한 모든 로터



밸런싱 용어

- **Unbalance**
  - Unit: g·mm

U = m x r

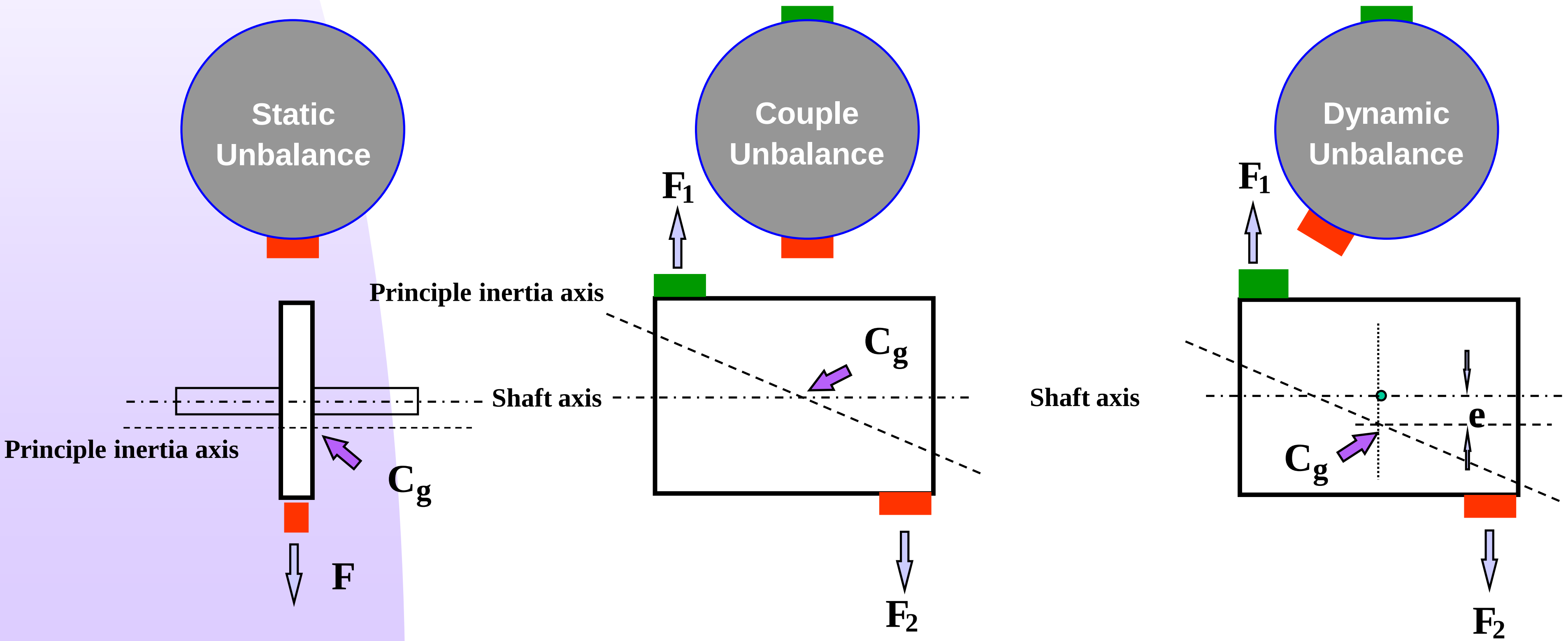


m = unbalance mass (g)

r = distance from unbalance mass to shaft/rotor centerline (mm)

밸런싱 용어

- **Unbalance**
  - Static Unbalance
  - Couple Unbalance
  - Dynamic Unbalance



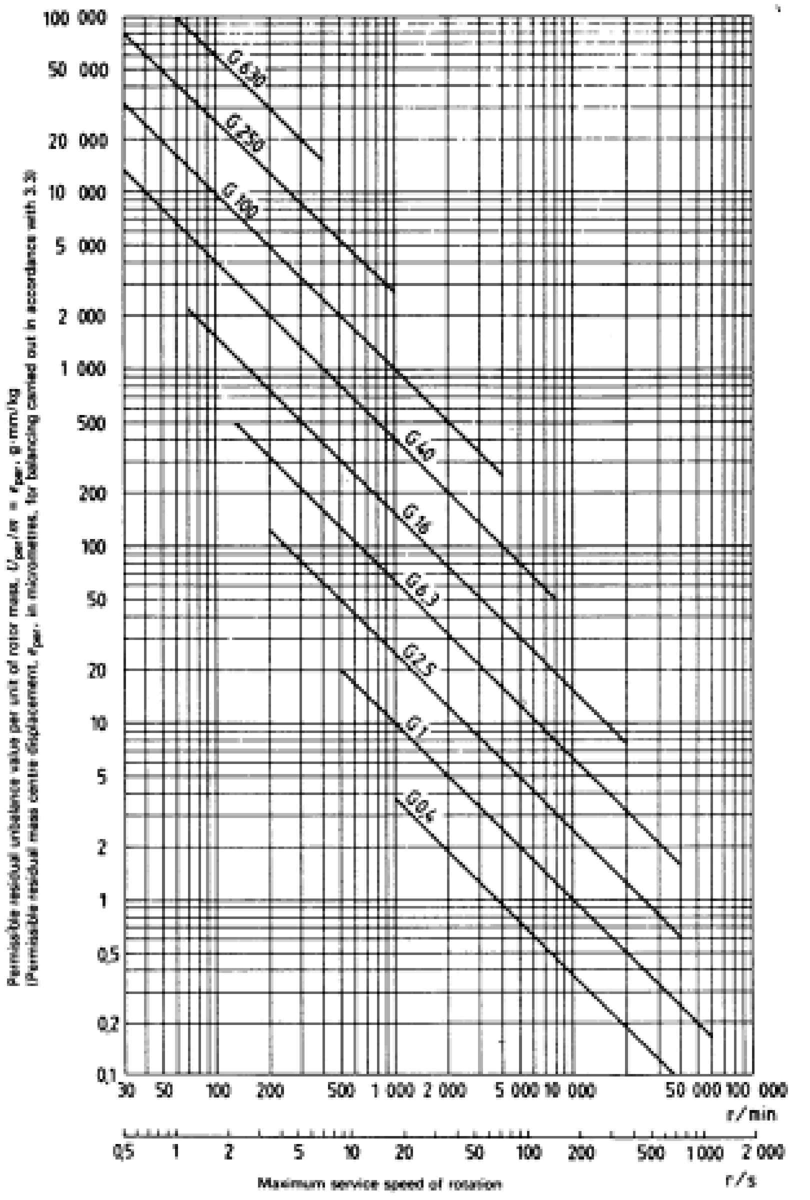
허용잔류불평형

- **Balancing Grade for Rigid Rotor**
  - ISO 1940
  - API

$$U_{\max} = 6350 \frac{W}{N} \ [\mathrm{g \cdot mm}]$$

$$W = \text{Journal static load [kg]}$$

$$N = \text{Max. speed [rpm]}$$



허용잔류불평형

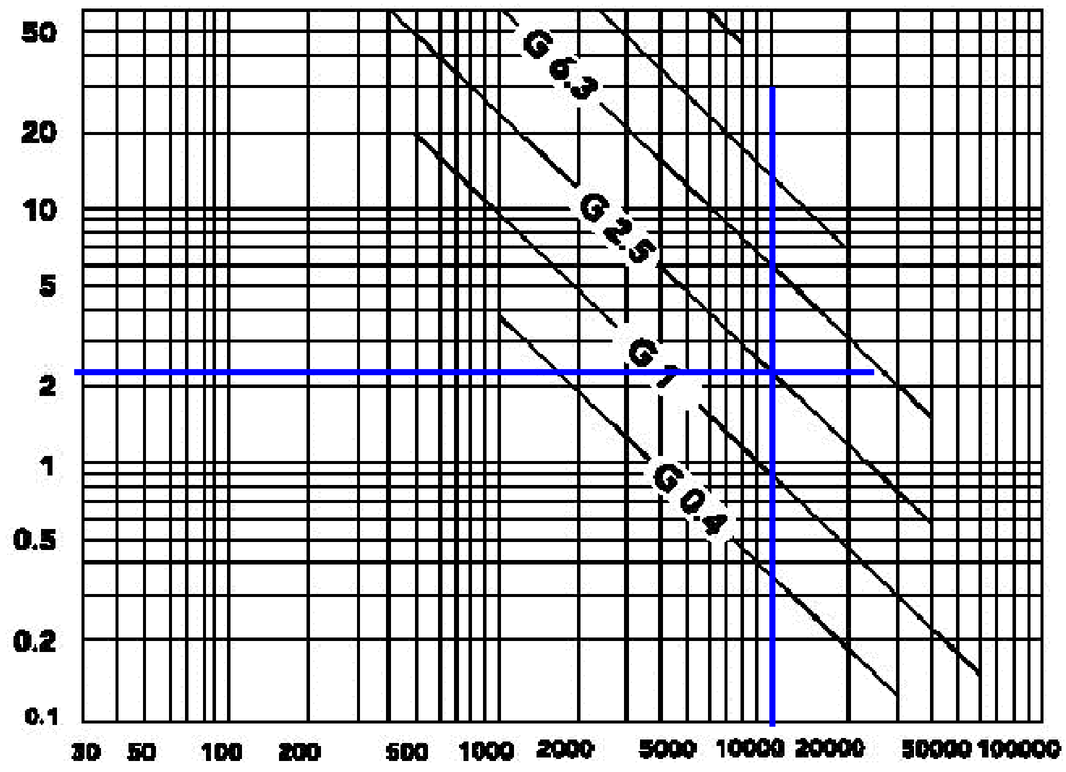
- **Balancing Grade for Rigid Rotor**
  - ISO 1940

Grade	Application
G 16	Drive shafts (propeller shafts) with special requirements. Parts of crushing machinery. Parts of agricultural machinery. Slurry or dredge pump impeller. Individual components of engines (gas or diesel) for cars, trucks and locomotives. Crankshaft drives of engines with six or more cylinders under special requirements.
G 6.3	Parts or process plant machines. Fans. Fly wheels. Pump impellers. Machine tool and general machinery parts. Normal electrical armatures. Individual components of engines under special requirements Marine main turbine gears (merchant service).
G 2.5	Gas & steam turbines, including marine main turbines. Rigid turbo-generator rotors. Turbo-compressors. Machine tool drives. Medium and large electrical armatures with special requirements. Small electrical armatures. Turbine driven pumps.
G 1	Grinding machine drives. Small electrical armatures with special requirements.
G 0.4	Spindles, disks and armatures of precision grinders.

허용잔류불평형

- **Example for Turbine Rotor**
  - Rotor Weight 400 kg
  - Max. Speed 10,000 rpm
- **ISO 1940 G2.5**

$$U_{\max} = 2.4\mu m \times 400kg$$
$$= 960.0 \ [\mathrm{g \cdot mm}]$$



- **API**

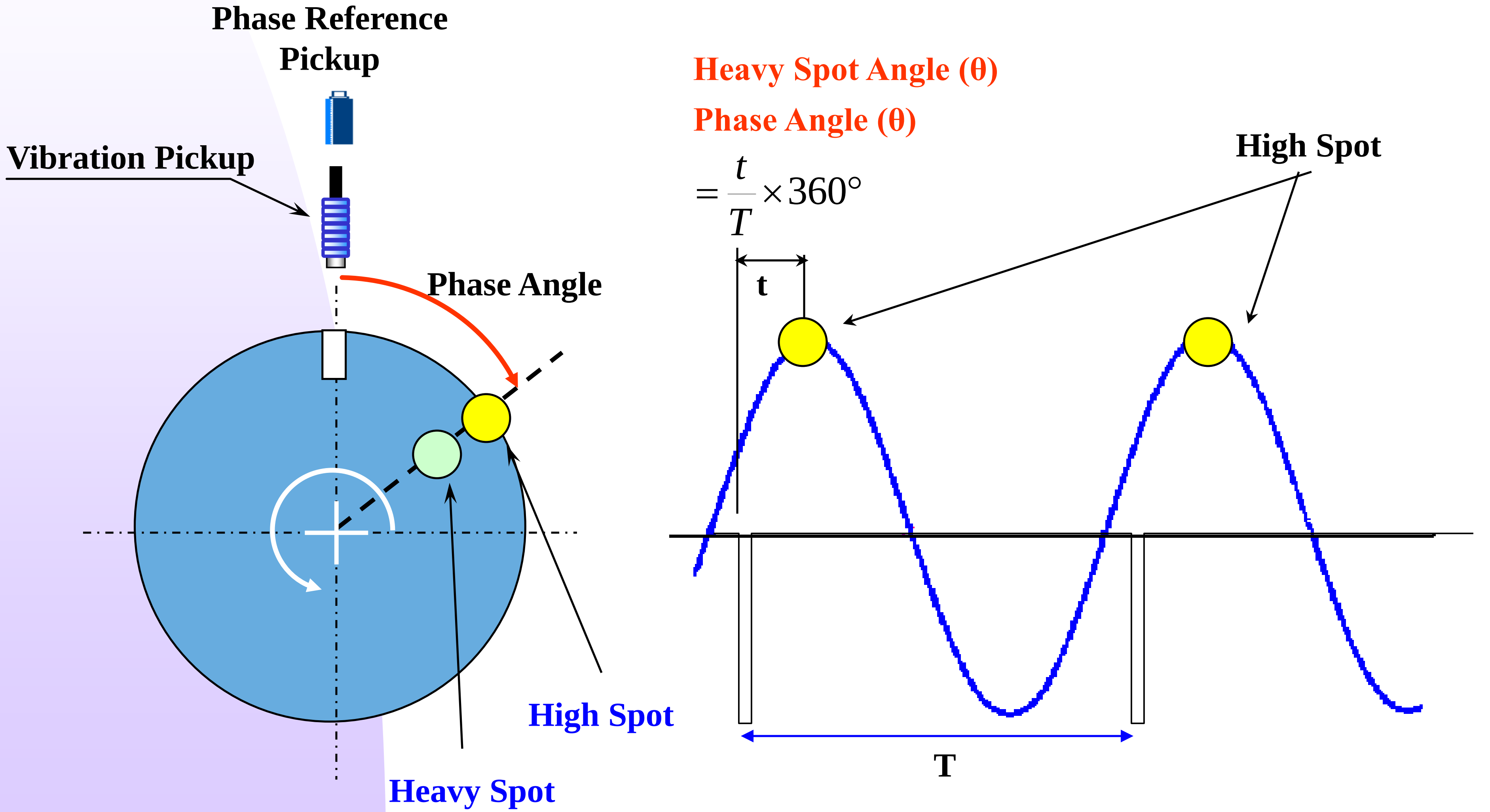
$$U_{\max} = 6350 \frac{200kg}{10000rpm}$$
$$= 127.0 \ [\mathrm{g \cdot mm}]$$

밸런싱 방법

- **Graphic Method: Single Plane**
  - Vector method
  - 4 Run method
  - Static couple method
- **Influence Coefficient Method: Multi Plane**
  - Standard influence coefficient method
  - Least square influence coefficient method
- **Modal Method**
  - Critical speed mode shape, Modal influence balancing coefficients

밸런싱 방법

- **Phase Angle**



밸런싱 방법

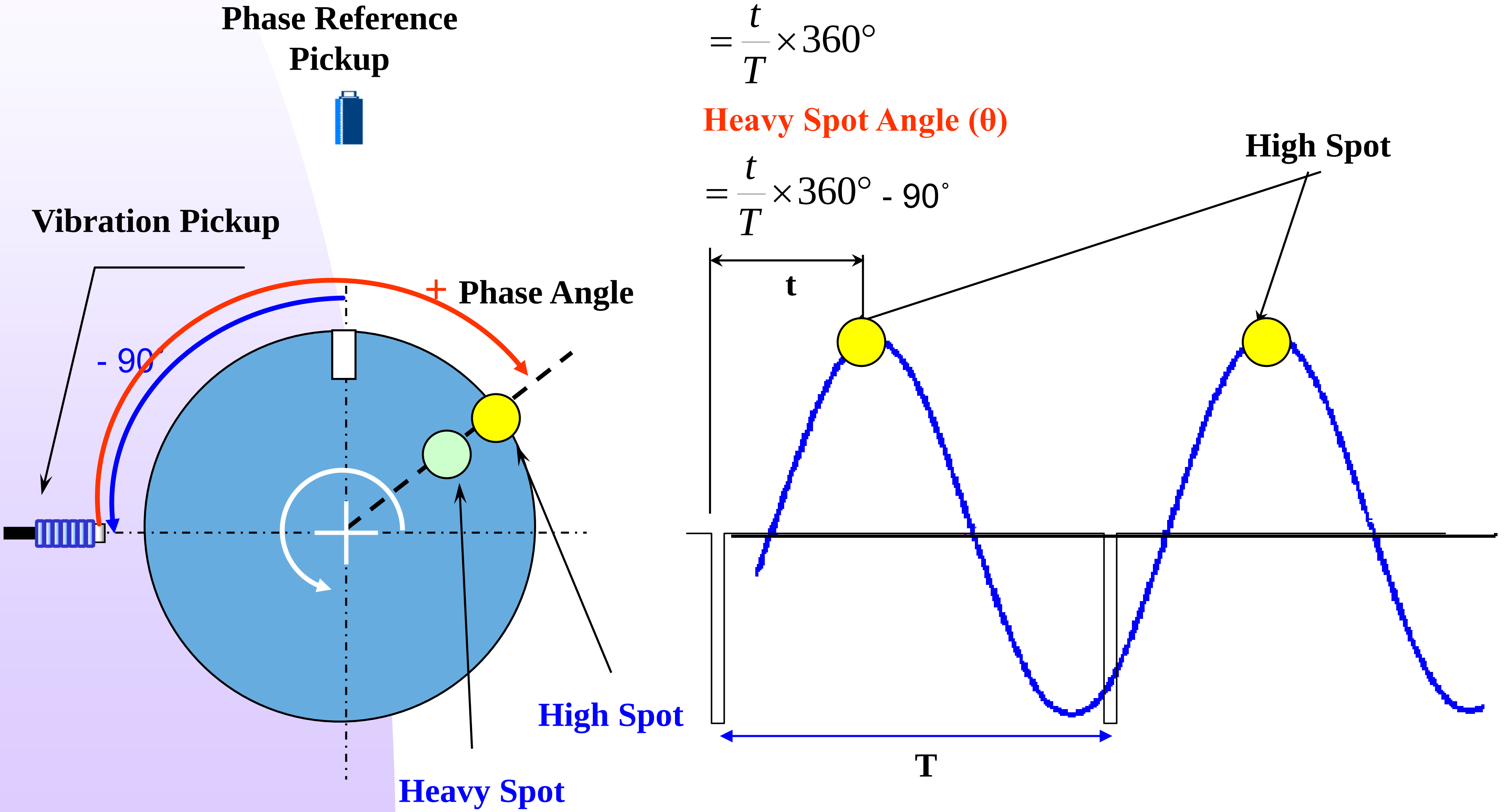
- **Phase Angle**

Phase Angle (θ)

$$= \frac{t}{T} \times 360°$$

Heavy Spot Angle (θ)

$$= \frac{t}{T} \times 360° - 90°$$



밸런싱 방법(Single plane)

- **Vector Method**

Z_o : 초기진동 벡터

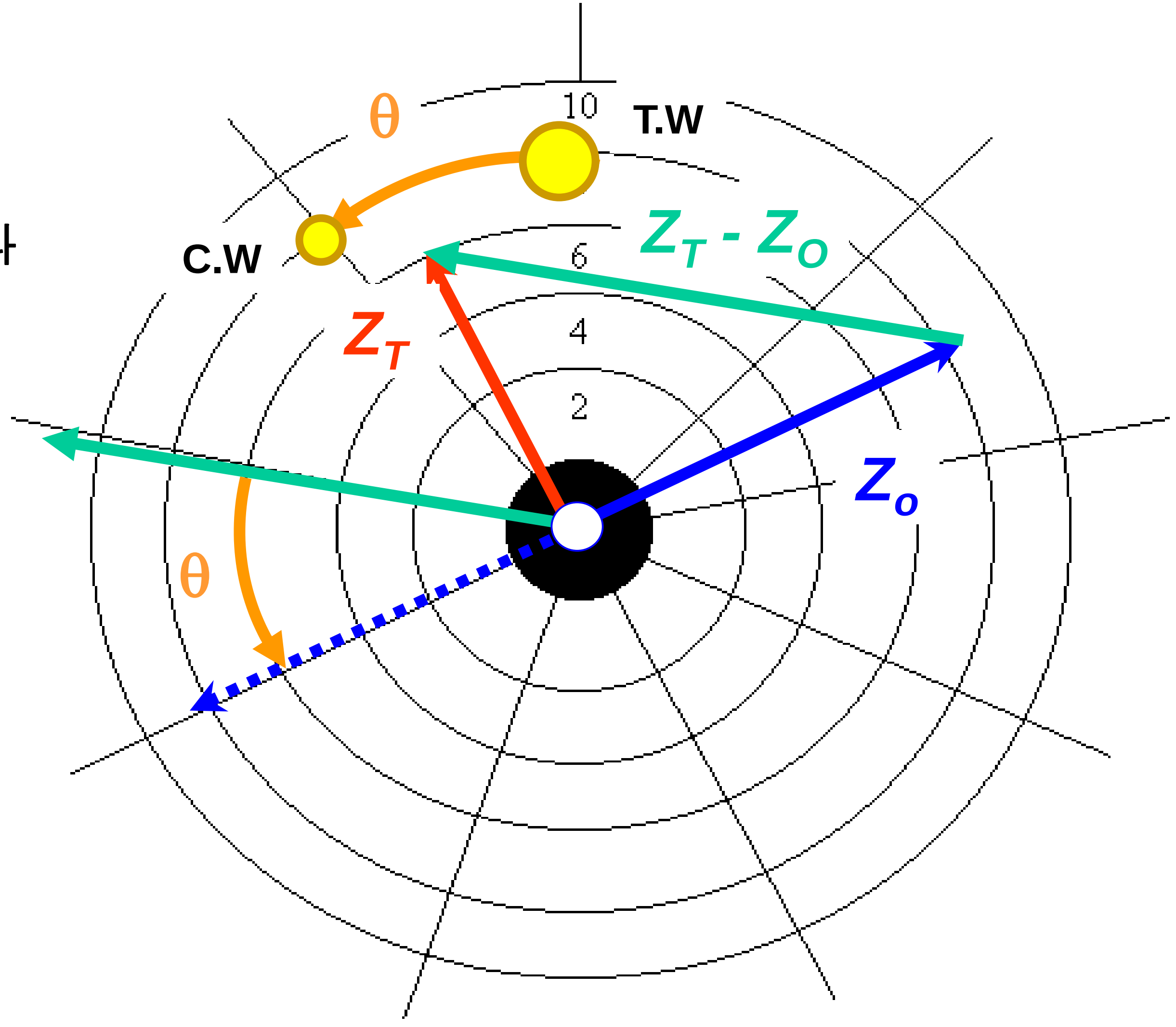
Z_T : 시험질량을 취부한

= Z_o+ $T.W$

$Z_o - Z_T$: 시험질량만의 효과

T.W : 시험질량

C.W : 수정질량



밸런싱 방법(Single plane)

- **Vector Method**

$$Z_0 = a \cdot U_0$$

$$Z_T = a \cdot \left(U_0 + U_T\right)$$

$$= a \cdot U_0 + a \cdot U_T$$

$$= Z_0 + a \cdot U_T$$

$$a = \frac{Z_T - Z_0}{U_T}$$

$$U_0 = \frac{a \cdot U_T}{Z_T - Z_0}$$

$Z_0 =$ 초기 진동 벡터

$Z_T =$ 시험 질량을 취부한 진동 벡터

$U_0 =$ 초기 불평형량

$U_T (W_T) =$ 시험 질량을 취부한 불평형량

$a =$ 영향계수

밸런싱 방법(Single plane)

- **Vector Method**

$$Z_0 = 25\angle 95^\circ$$

$$m_T = 10g\angle 180^\circ$$

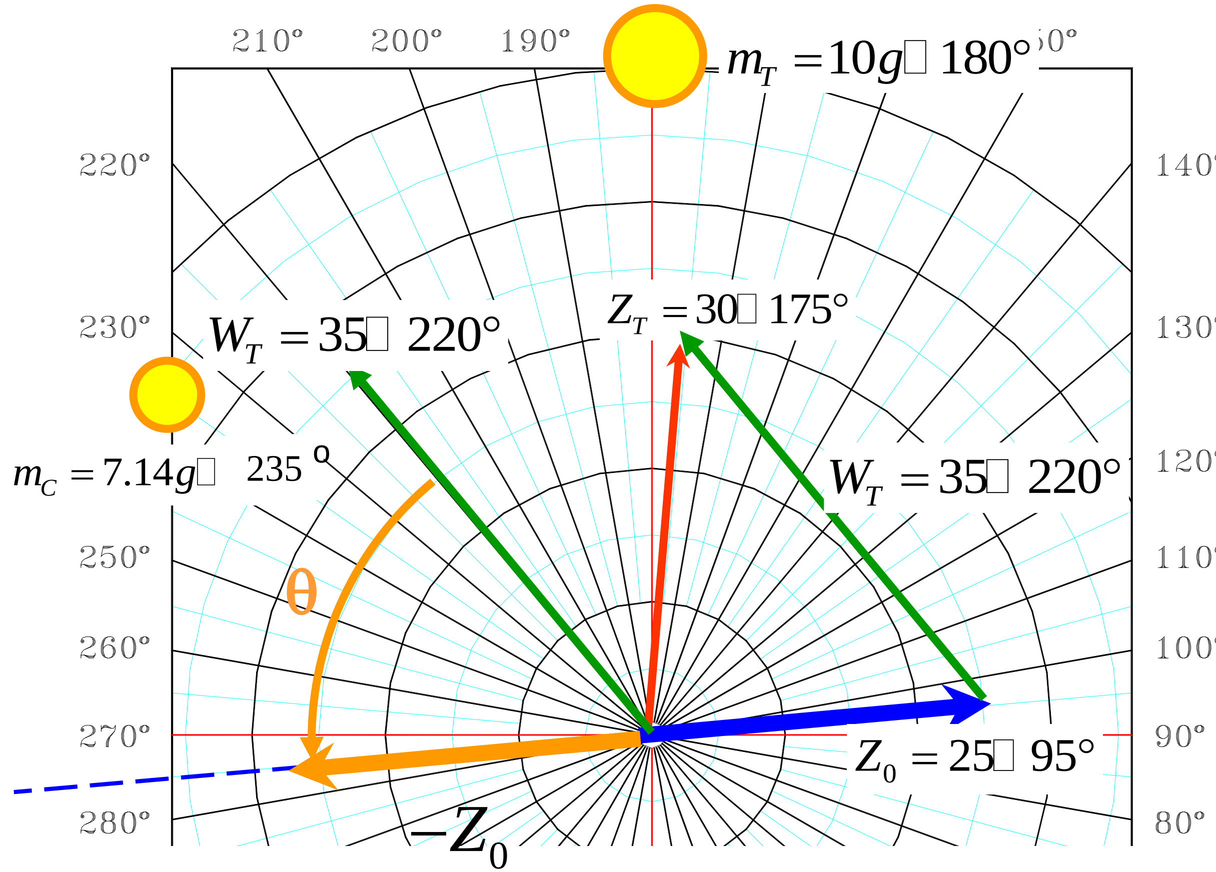
$$Z_T = 30\angle 175^\circ$$

$$W_T = 35\angle 220^\circ$$

$$10g : 35\mu m = m_C : 25\mu m$$

$$m_C = \frac{10g \times 25\mu m}{35\mu m}$$

$$= 7.14g\angle m_c$$

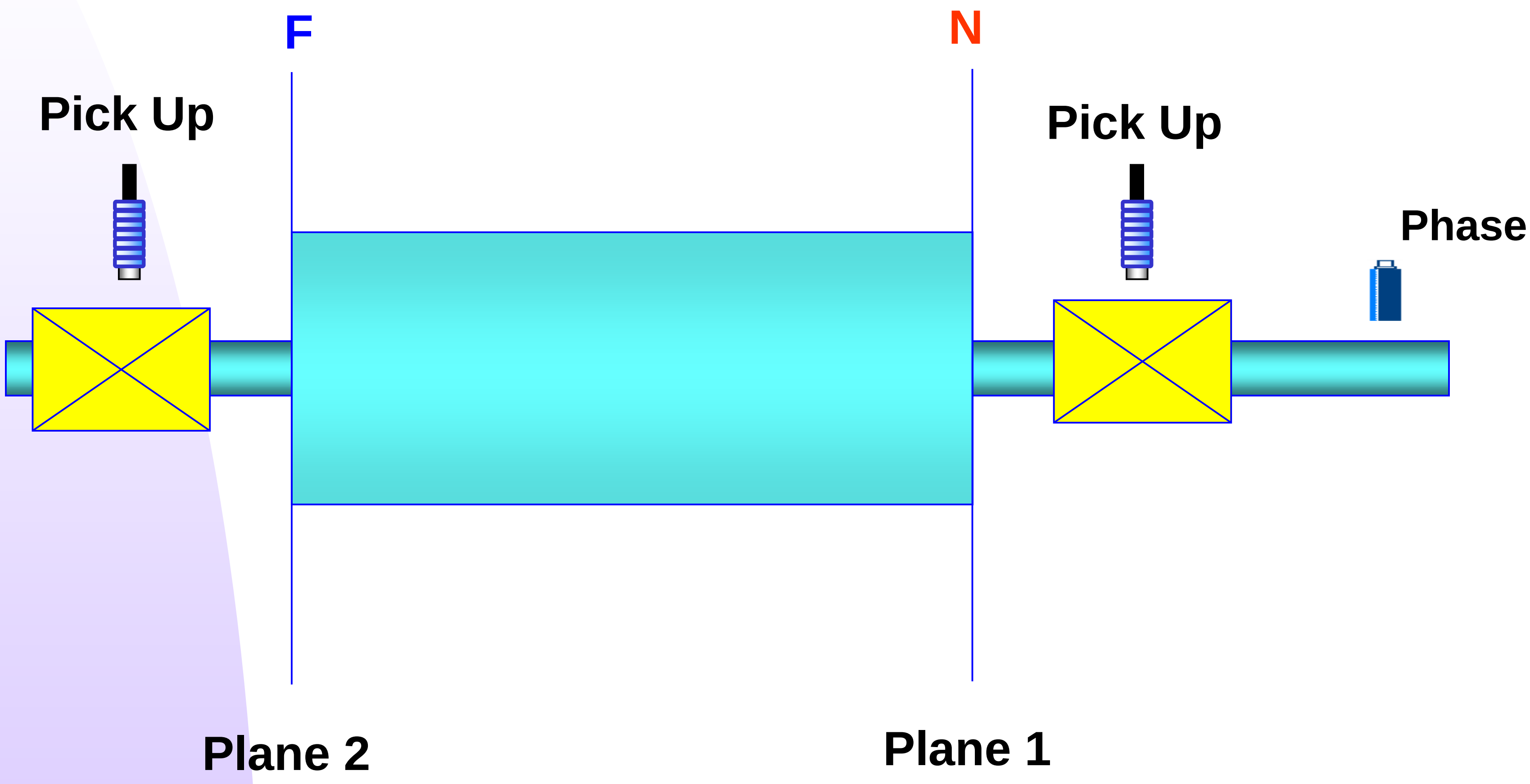


$$m_C = 7.14g\angle 235$$

$$\angle m_c - \angle m_T = \angle(-Z_0) - \angle W_T$$

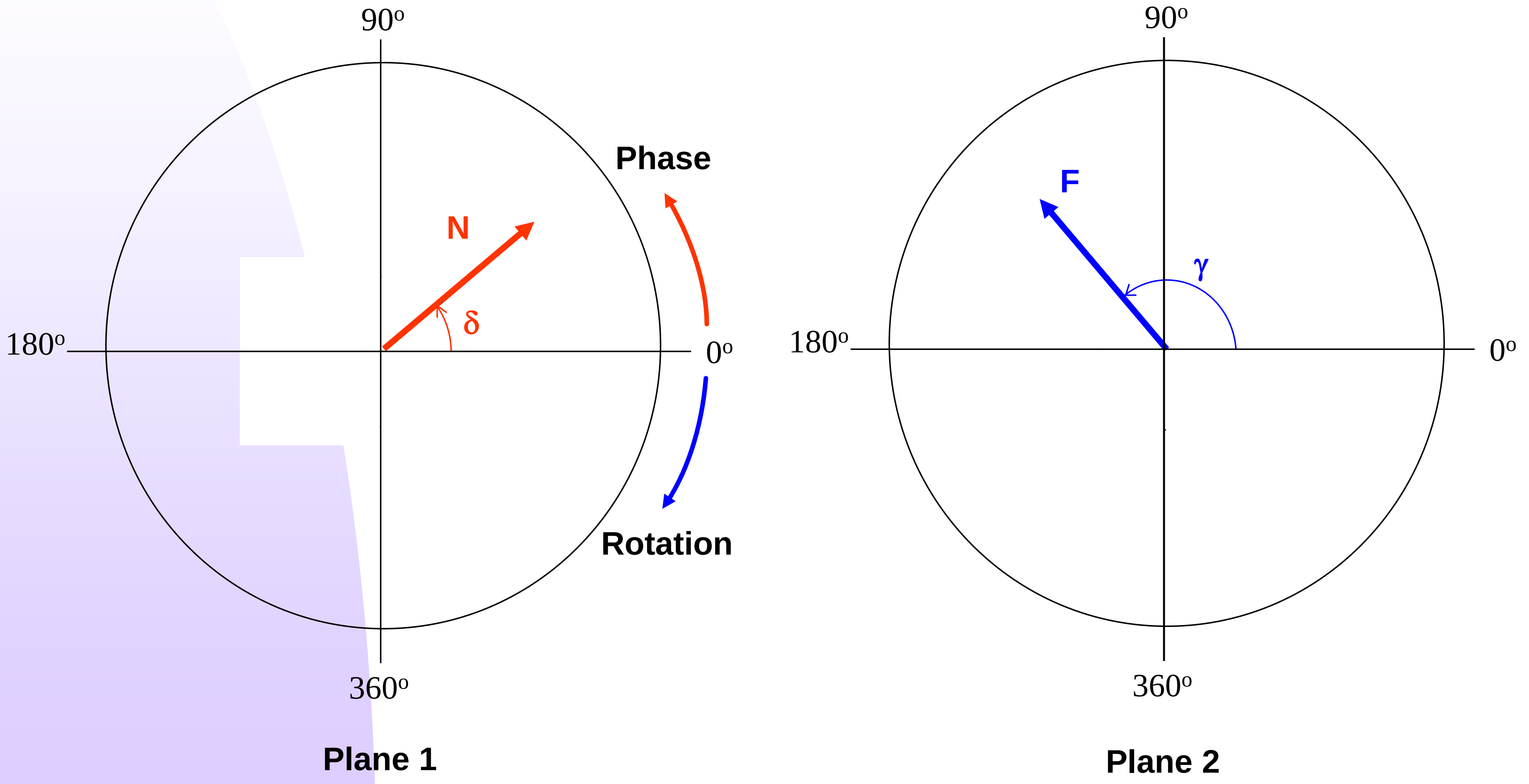
$$\angle m_c = \angle m_T + \angle(-Z_0) - \angle W_T = 180^0 + (95^0 + 180^0) - 220^0 = 235^0$$

밸런싱 방법(Two plane)



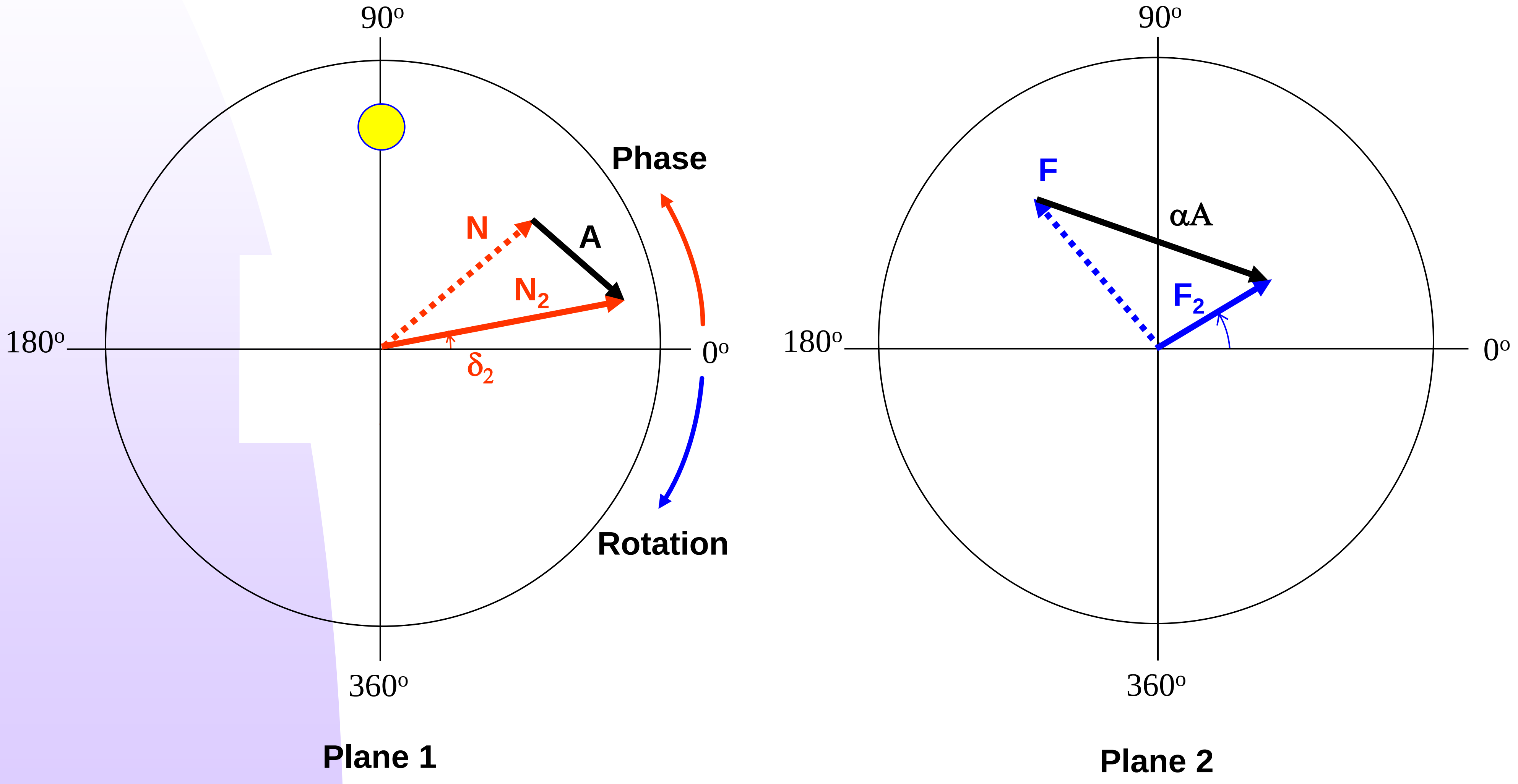
밸런싱 방법(Two plane)

- **Initial vibration**



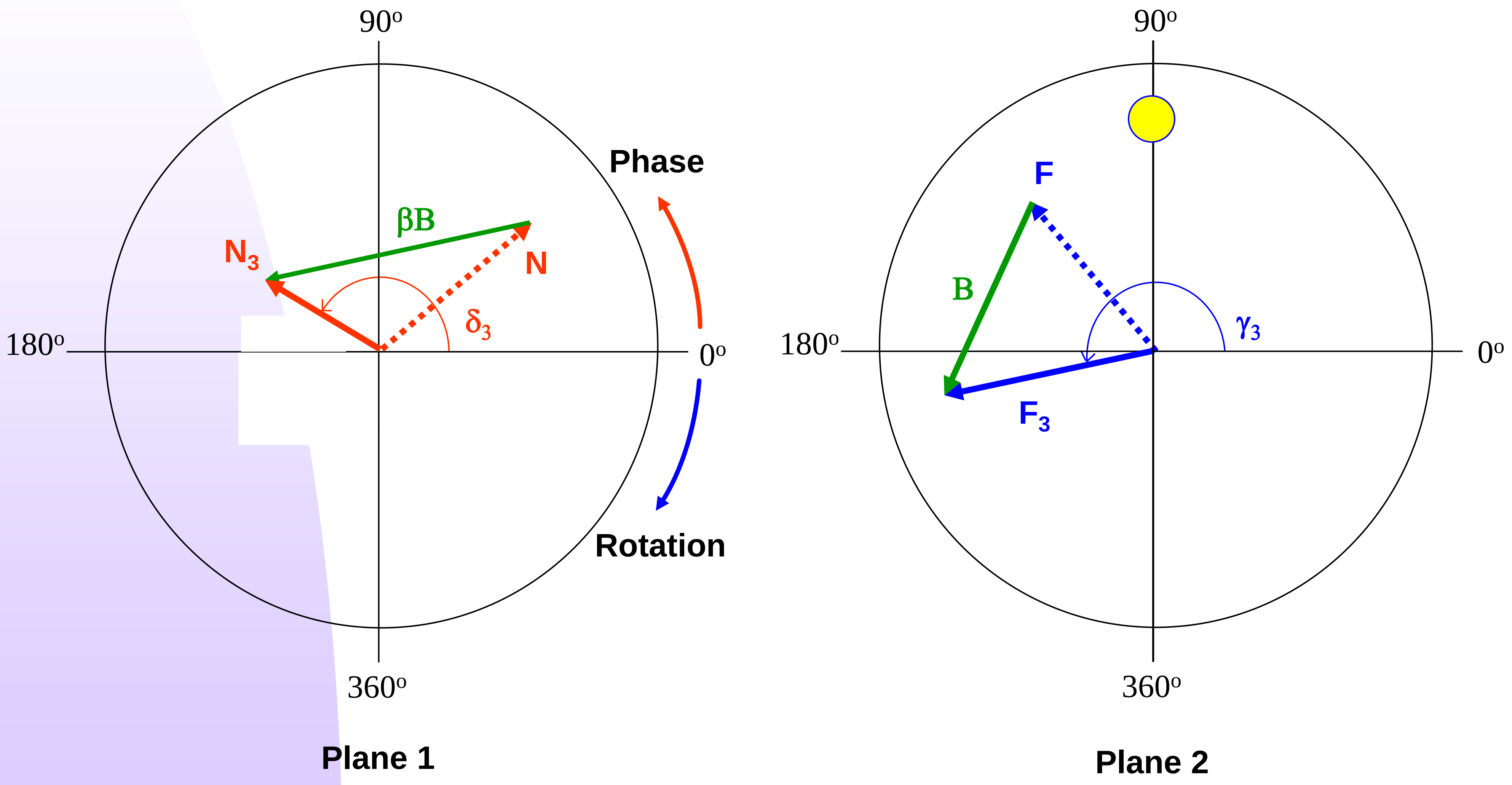
밸런싱 방법(Two plane)

- **Trial weight – plane 1**



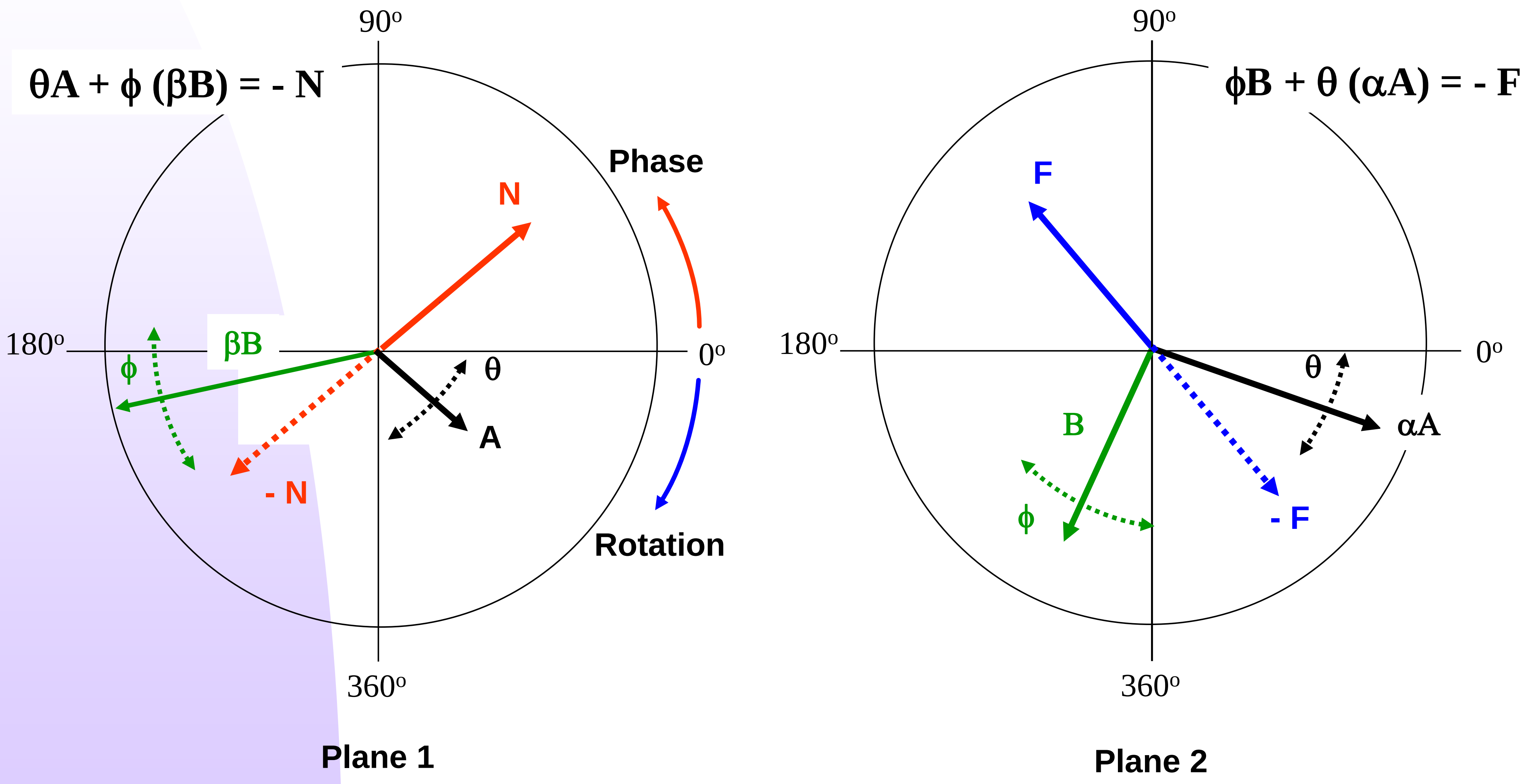
밸런싱 방법(Two plane)

- **Trial weight – plane 2**



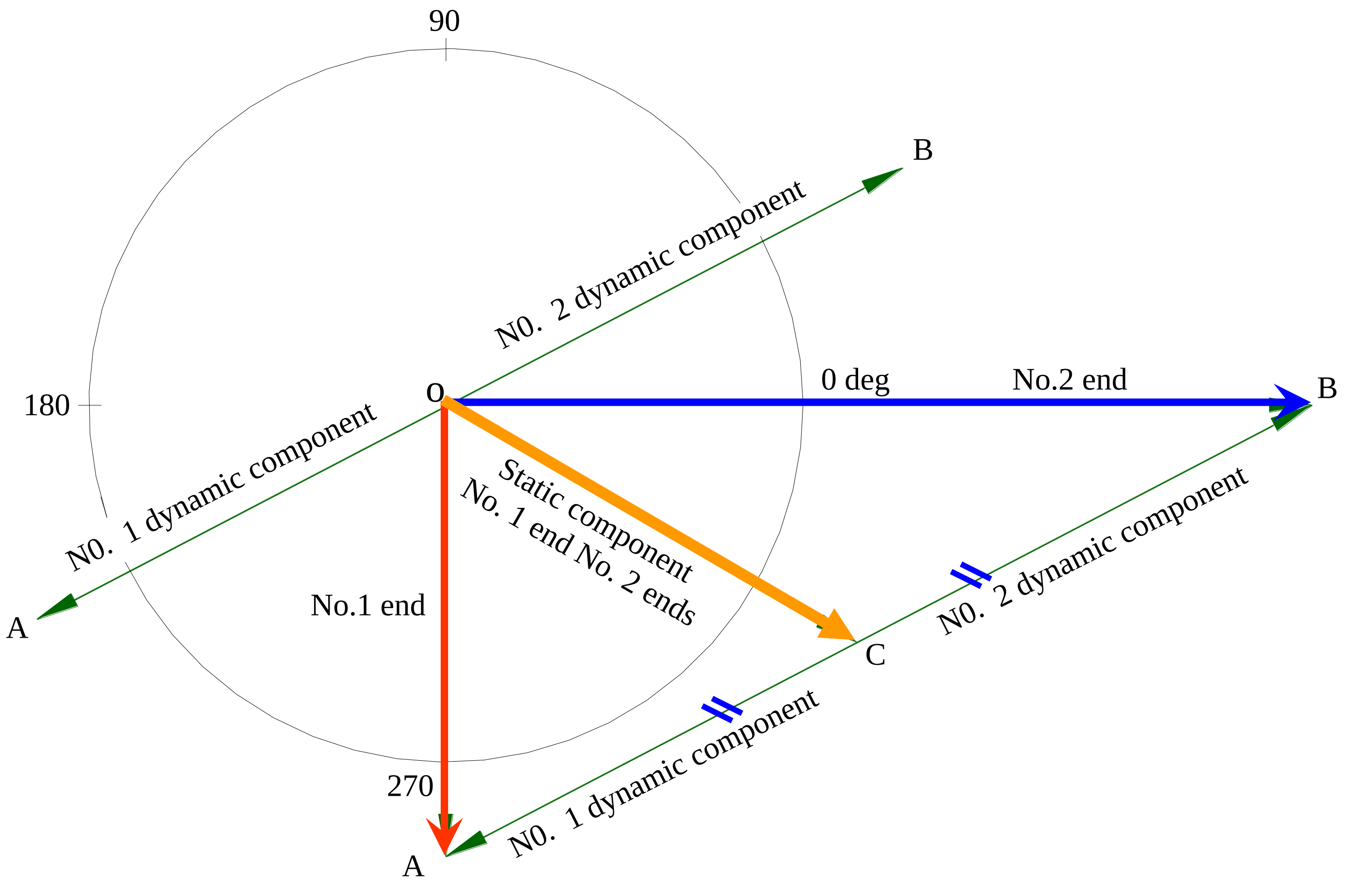
밸런싱 방법(Two plane)

- **Trial weight – plane 2**



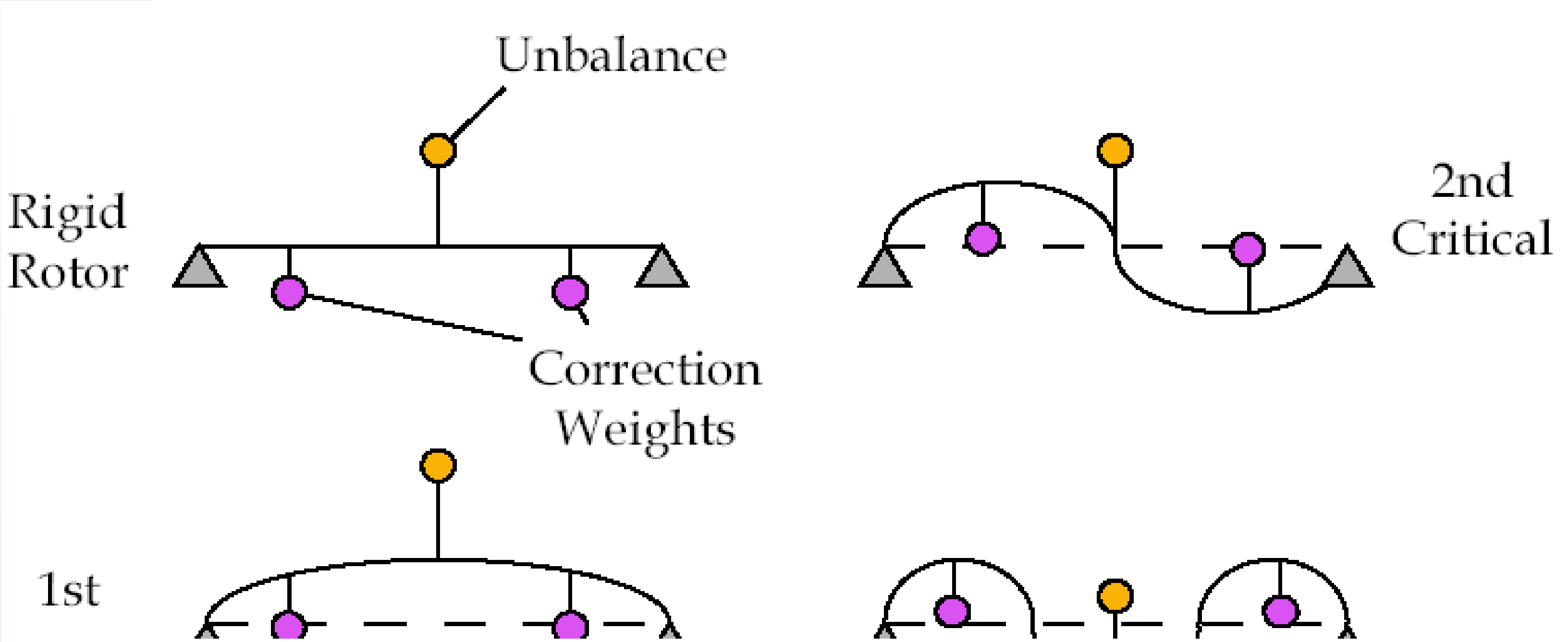
밸런싱 방법

- **Static/Couple Method**



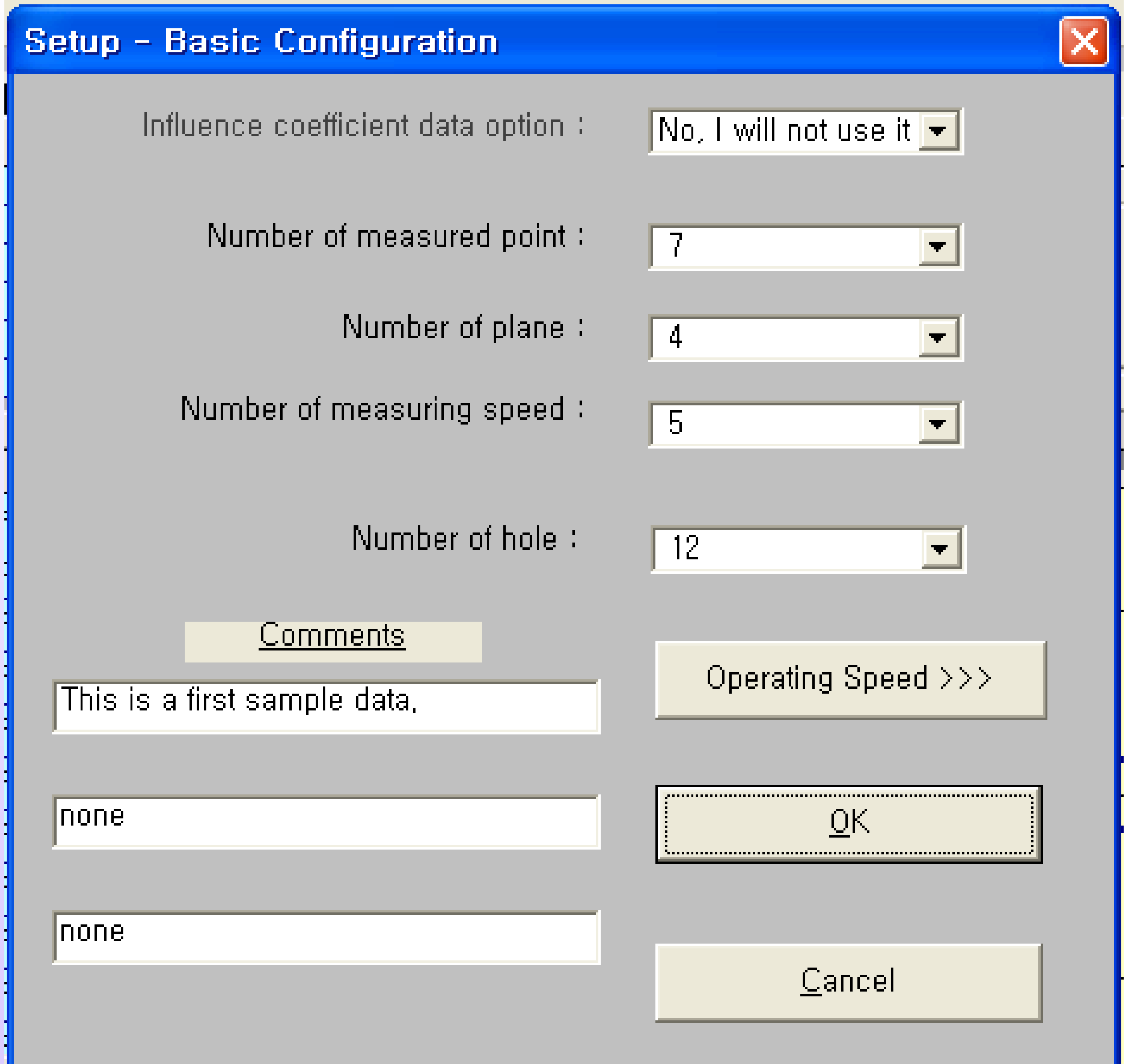
밸런싱 방법

- **Modal Balancing**
  - Mode Shape
  - Modal Distribution



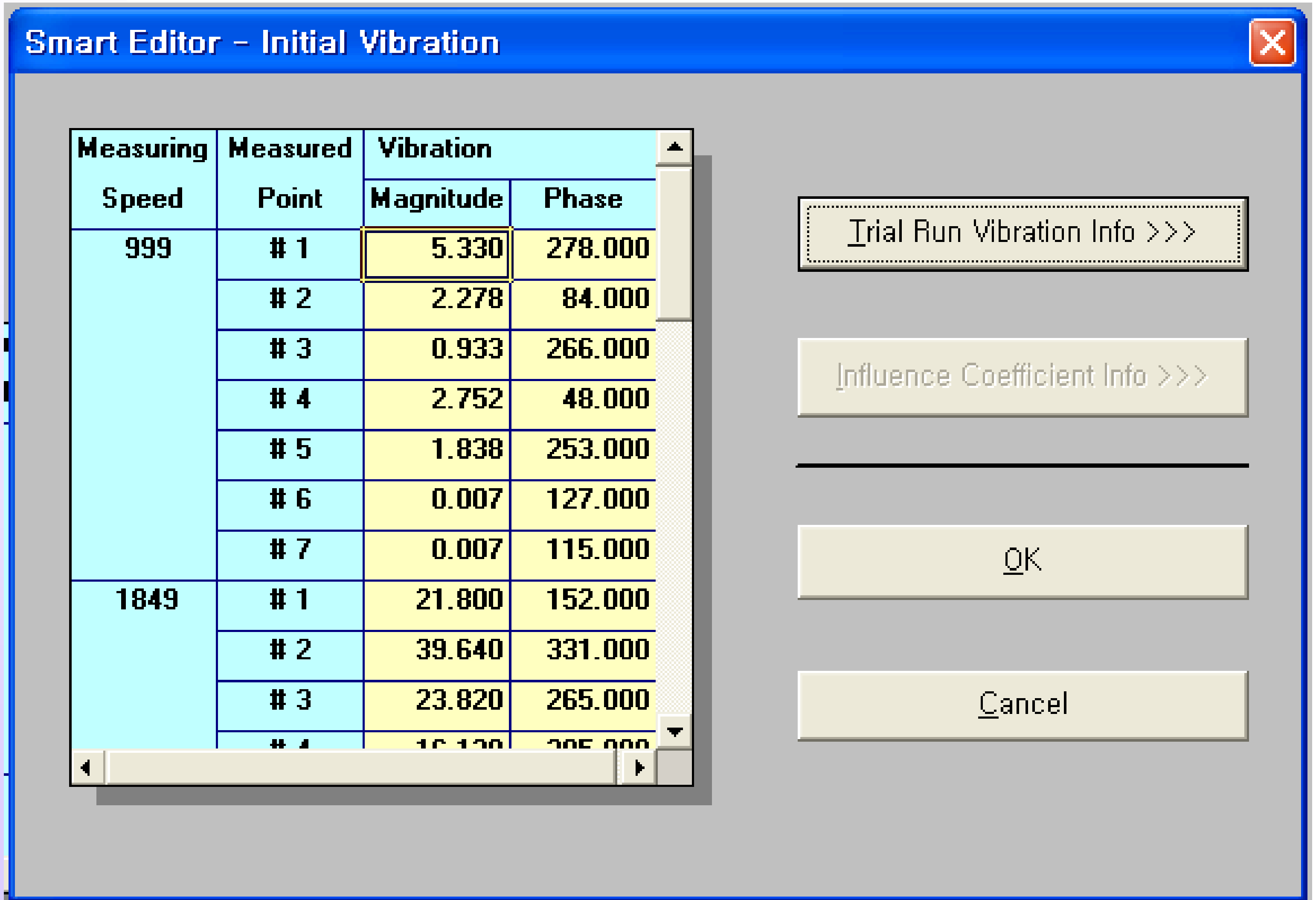
밸런싱 프로그램

■ **Input Module**



밸런싱 프로그램

- **Input Module**



Measuring Speed	Measured Point	Vibration Magnitude	Vibration Phase
999	# 1	5.330	278.000
	# 2	2.278	84.000
	# 3	0.933	266.000
	# 4	2.752	48.000
	# 5	1.838	253.000
	# 6	0.007	127.000
	# 7	0.007	115.000
1849	# 1	21.800	152.000
	# 2	39.640	331.000
	# 3	23.820	265.000

밸런싱 프로그램

- **Input Module**

Smart Editor - Trial Run Vibration

Measuring Speed	Measured Point	Plane # 1 Magnitude	Plane # 1 Phase	Plane # 2 Magnitude	Plane # 2 Phase
999	# 1	8.355	31.000	14.760	278.000
	# 2	19.710	286.000	5.907	283.000
	# 3	7.245	134.000	2.468	138.000
	# 4	15.220	283.000	8.190	290.000
	# 5	5.891	134.000	3.094	155.000
	# 6	0.042	336.000	0.010	344.000
	# 7	0.039	343.000	0.018	340.000
1849	# 1	25.400	313.000	25.590	253.000
	# 2	33.970	135.000	17.000	51.000
	# 3	21.870	64.000	8.518	321.000

Plane #	Trial Mass Magnitude	Trial Mass Angle
1	25.80	333.00
2	93.60	142.00
3	75.80	105.00
4	82.30	105.00

OK

Cancel

밸런싱 프로그램

■ **Output Module**

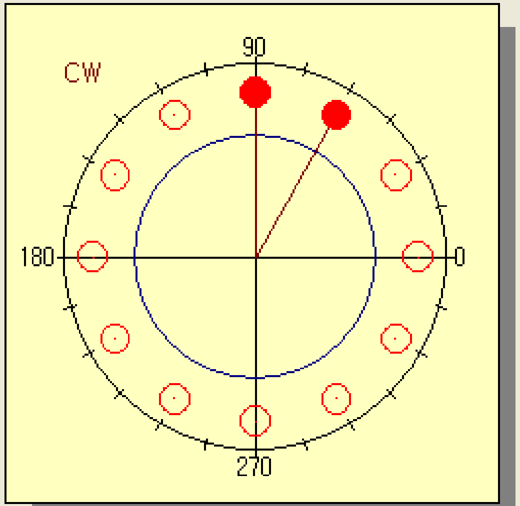
Balancing Wizard Beta 3 - [C:₩Program Files₩Balancing Wizard Beta 3₩default.bal]

File Wizard Report Misc Help

Correction Weight | Equalized Correction Weight

Plane	Correction Mass Magnitude	Correction Mass Angle	Split 1 Mass Magnitude	Split 1 Mass Angle	Split 2 Mass Magnitude	Split 2 Mass Angle
#1	12.40	68.63	9.04	60.00	3.72	90.00
#2	185.37	170.54	60.92	150.00	130.09	180.00
#3	211.51	351.14	65.13	330.00	152.59	360.00
#4	110.81	186.08	89.85	180.00	23.48	210.00

Measuring Speed	Measured Point	Res.Vib. Magnitude	Res.Vib. Phase
999	# 1	20.094	261.500
	# 2	11.826	327.300
	# 3	5.216	178.400
	# 4	12.347	319.300
	# 5	4.566	179.500
	# 6	0.025	23.400
	# 7	0.025	12.900
1849	# 1	20.048	296.100
	# 2	20.101	196.900



Status : | 2004-02-19 | 오후 10:43

회전체 분류(ISO)

- Class 1 : Rigid Rotor : These rotors may be balanced in any two arbitrary axial planes and will remain in balance throughout the operating speed range

  (ex., Gear wheel etc.)

- Class 2 : Quasi-flexible Rotors : These rotors are not perfectly rigid but may be adequately balanced in a low-speed balancing machine and will maintain smooth operation throughout the speed range

  (ex., Shaft with grinding wheel, Jet-engine compressor rotor, Printing-press roller, Computer memory drum, Five-stage centrifugal pump, Multistage pump impeller, Impeller pump, Steam turbine rotor)

→ **Single and two plane constant-speed balancing is usually adequate**

회전체 분류(ISO)

- Class 3 : Flexible Rotors : These rotors cannot be balanced in a low-speed balancing machine and require one or more high-speed trim plane corrections

  (ex : Generator rotor etc.)

- Class 4 : Flexible-attachment Rotors : These rotors have components within themselves or flexibly attached

  (ex : Rotor with centrifugal switch)

- Class 5 : Single-speed Flexible Rotors : These rotors could be class 3 flexible rotors but are balanced for operation at one speed only

  (ex : High-speed motor)

A least-squared-error influence coefficient or combined modal technique is preferred