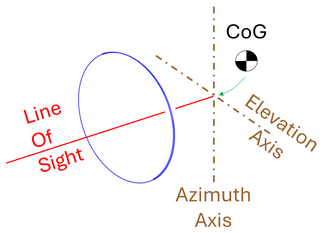
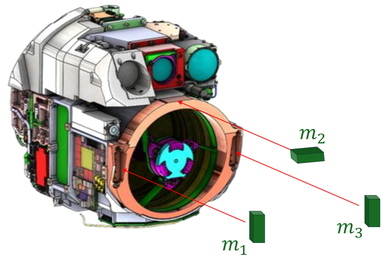
Automated Optical Bench Static Balancing Procedure Using the Discrete Linear Programming Algorithm

Ilia Rapoport, PhD, Elbit Systems LTD

Static Balancing

Important in Line of Sight stabilization applications to reduce disturbance torque due to high frequency linear vibration beyond the control loop bandwidth.



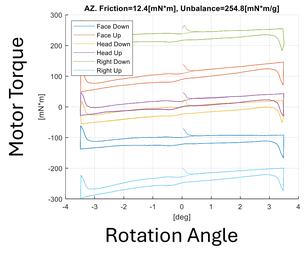


By adding balancing weights

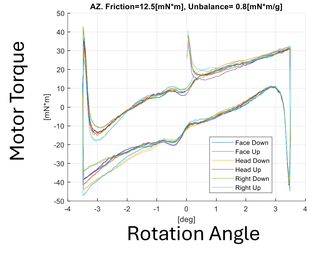
Unbalance measurements

Back & Forth rotation in various orientations wrt local vertical

Unbalanced

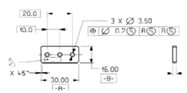


Balanced



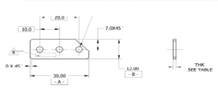
Discrete balance weights

ITEM NO	PART IDENTIFICATION NO	THK	WEIGHT
1	L958-2005-60 REV_	1.50	12.5 gr
2	L958-2006-60 REV_	2.00	17 gr
3	L958-2007-60 REV_	3.00	25 gr
4	L958-2009-60 REV_	6.00	50 gr



TABLE

ITEM NO	PART IDENTIFICATION NO.	THK	WEIGHT
1	4750-2005-00	1.50	9
2	4750-2006-00	3.00	18
3	4750-2007-00	6.00	35
4	4750-2010-00	8.00	47

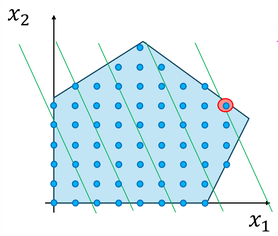


Old method: **Manually**

Hours of calibration
by special trained personnel 😢

Required: Automated balancing process

Obvious Method: **Discrete Linear Programming**



Cost: Total added mass

$$\sum \Delta m_n k_n$$

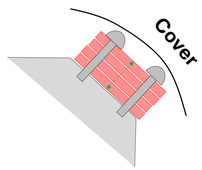
Constraints:

Nonnegative weights

$$k_n \geq 0$$

Max Permitted Thickness

$$\sum \Delta L_n k_n \leq L_n^{\max}$$



Max Unbalance

$$-H_{\max} \leq h(k_1, k_2, \dots, k_N) + H \leq +H_{\max}$$

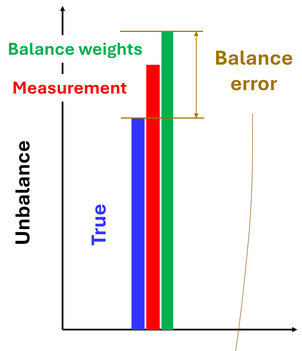
Problems: **Uncertainties**

Motor Torque Measurements: **10%**

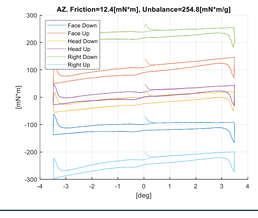
Balance weights: **5%**

Unbalance to fix: **~250mN·m/g**

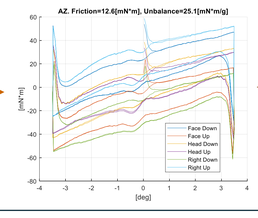
Required tolerance: **< 1÷5mN·m/g**



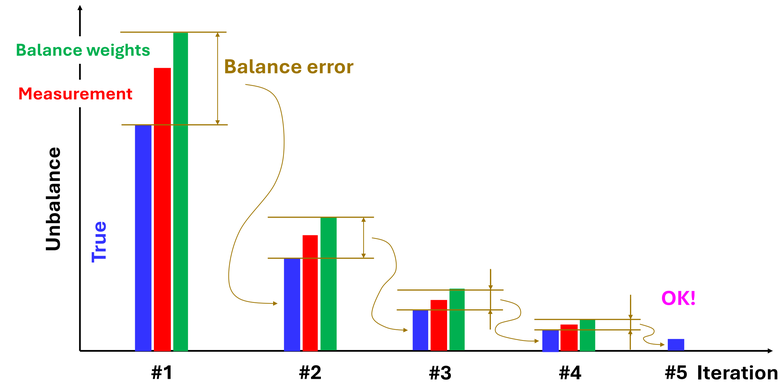
255 mN·m/g



25 mN·m/g



Solution: Iterative Process



Cost: Total change in balancing weights

$$\sum \Delta m_n k_n^+ + \sum \Delta m_n k_n^-$$

Added weights — Removed weights

Constraints:

Nonnegative weights

$$0 \leq k_n^+$$
$$0 \leq k_n^- \leq K_n^{old}$$

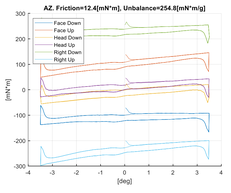
Max Permitted Thickness

$$\sum \Delta L_n k_n^+ - \sum \Delta L_n k_n^- \leq L_n^{\max}$$

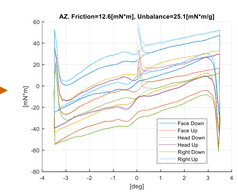
Max Unbalance

$$-H_{\max} \leq h(k_1^+, k_2^+, \dots, k_n^+, k_n^-, \dots) + H \leq +H_{\max}$$

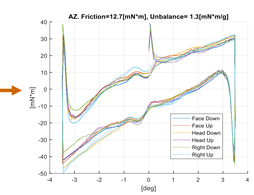
Unbalanced
255 mN·m/g



1st iteration
25 mN·m/g



2nd iteration
0.8 mN·m/g



Less than an hour of calibration
No special training needed

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