P08

導電性テザーの残留歪みを考慮した数値計算モデルの評価

The Evaluation of the Nonlinear Tether Numerical Simulation Model Considered Residual Strain

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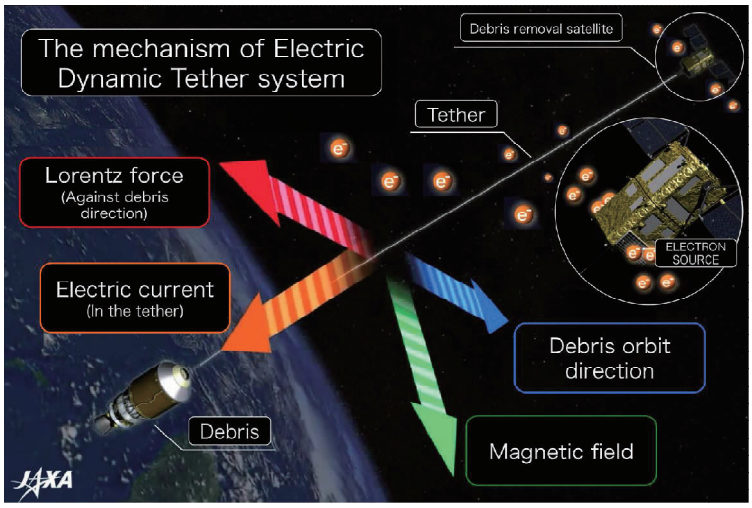
スペースデブリの総数が年々増加し、積極的な除去が必要な状況になっている。宇宙航空研究開発機構(JAXA)では、スペースデブリ除去のための推進系として導電性テザー推進(EDT 推進)の研究を進めている。これまでテザー数値シミュレーションにおいて、テザー引張時には力と伸びが比例せず、圧縮時にはバネ力が働かない非線形バネのモデルとして扱ってきたが、実際のテザーは塑性域まで引張された場合、塑性変形を起こし残留歪みが生じる。そこで、本研究ではテザーの残留歪みを検証するために実験を行い、残留歪みを考慮した非線形バネモデルを作成した。そして、特に残留歪みの影響が確認できる伸展急停止時において数値計算を行い、テザーのダイナミクスとエンドマスの挙動から残留歪みの影響を評価した。

As a countermeasure for suppressing space debris growth, the Japan Aerospace Exploration Agency (JAXA) is investigating an active space debris removal system that employs highly efficient electrodynamics tether (EDT) technology as its orbital transfer system. In numerical simulation to evaluate the tether dynamics, tether has been modeled as point masses connected by nonlinear springs and viscous dampers. The model is not considered the residual strain which occur on the actual tether at plastic deformation. In this paper, a nonlinear model considering residual strain is developed based on the results of tensile tests. Then, numerical simulations are conducted to investigate the effects of nonlinearity and residual strain. The results confirm that it is necessary to consider the nonlinearity and the residual strain in the numerical simulation when strong tension is applied on the tether such as in the case of unintentional stopping of tether deployment at a short length.



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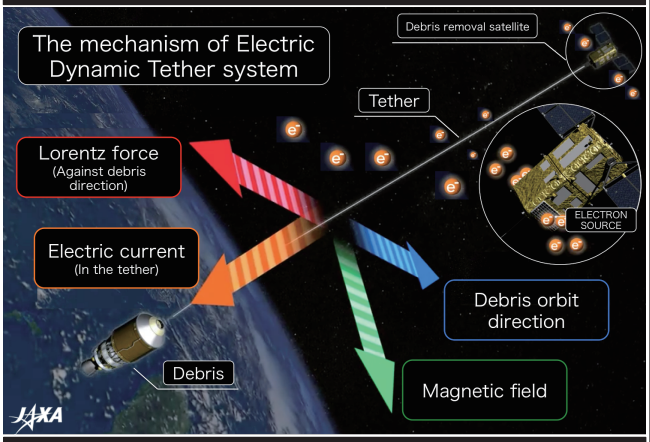
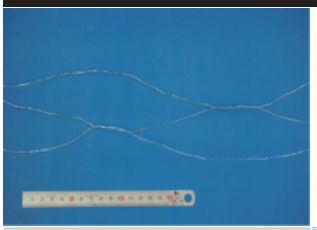
THE EVALUATION OF THE NONLINEAR TETHER NUMERICAL SIMULATION MODEL CONSIDERED RESIDUAL STRAIN

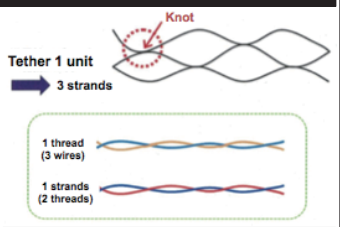
○Shohei Kudo, Mashisa Yanagisawa(UEC), Satomi Kawamoto, Kentaro Iki(JAXA)

1. JAXA investing the Electrodynamic tether system (EDT) for active debris removal



2. The consist of electrodynamic tether


Al-SUS net wire tether



Consist of tether

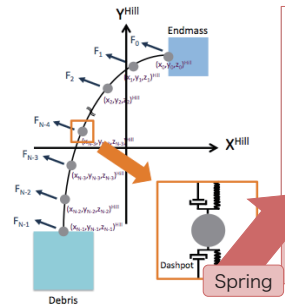
Tether's structure is "net tether". Tether consist 3 strands. One strand is composed of four aluminum wires and two stainless wires.

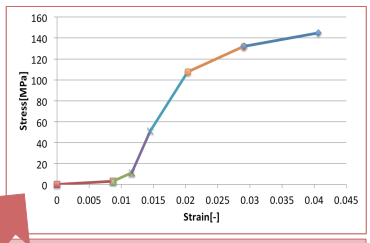
This net structure has high resistivity against the impacts of small debris.

Tether has "bare" surface, which has electric conductivity and electron collection from the ambient plasma through its surface.

3. EDT numerical simulation model overview

Tether has been modeled as point masses connected by liner springs and dashpot.

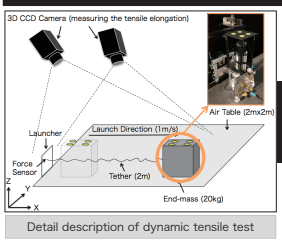




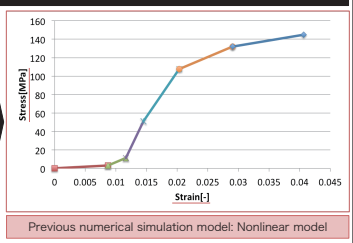
Previous simulation spring model : Nonlinear model

In earlier studies, we showed the necessity of considering nonlinear effect on tether affected by strong tension in tether deployment stopped unintentionally without any braking force.

4. The problem of previous nonlinear model



Detail description of dynamic tensile test



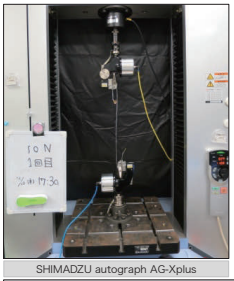
Previous numerical simulation model: Nonlinear model

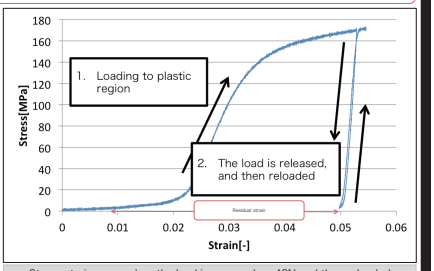
Previous study If the deployment of tether suddenly stops in orbit, tether is affected by impulsive force. The nonlinear model was built from stress-strain curve measured in dynamic tensile test.

Problem The Nonlinear model does not consider the residual strain The actual tether is affected by the residual strain, when the tether is deformed by the strong tension.

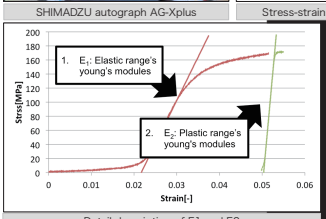
5. Building new numerical simulation model from the tensile test for measuring residual strain

Purpose In this research, a nonlinear model considering residual strain is developed based on the results of tensile tests and dynamic tensile tests of the tether.

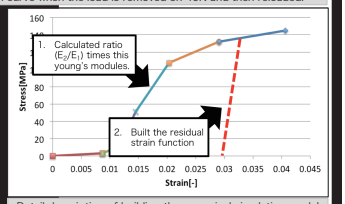

SHIMADZU autograph AG-Xplus



Stress-strain curve when the load is removed on 40N and then reloaded.

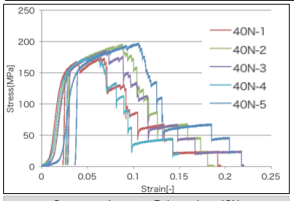


Detail description of E1 and E2

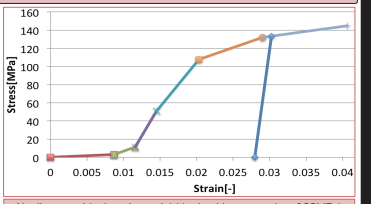


Detail description of building the numerical simulation model

Building new numerical simulation model



Stress-strain curve, Released on 40N



Nonlinear residual strain model (the load is removed on 138MPa)

The starting position of residual strain function is determined by the stress in the completion of the tether's deployment.

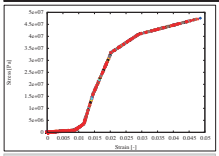
6. Deployment tether numerical simulation with new numerical simulation model

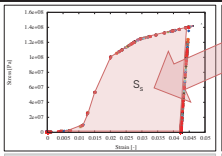
Simulation conditions			
Condition		Unit	Value
Time step		[Sec]	5.0×10^{-7}
Orbit	Altitude	[Km]	400.0
Mother satellite	Mass	[Kg]	12300

End-mass (DRS)	Mass	[Kg]	19.3
	Initial Velocity	[m/s]	1.0
Tether	Length	[m]	10
	Liner density	[g/m]	1.0
	Mass point	[-]	21
	Damping ration	[-]	0.02

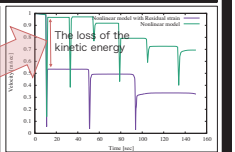
The tether is very short length and the brake intentionally does not work, inducing the large tension and tethers nonlinearity in numerical simulation.

7. Numerical simulation results verifying the effect of residual strain of the tether


Stress-strain curve. (Numerical simulation model: Nonlinear model)



Stress-strain curve. (Numerical simulation model: Nonlinear residual strain model)



The time history of end-mass's velocity

The end-mass's velocity slows down in the nonlinear residual strain model, since the kinetic energy is translated into the strain energy.

The energy loss is equal to area (Ss) inside the Stress-strain loop. Ss are 4.145[J]. The kinetic energy is lost about 5.867[J], which value is almost equal to the strain energy.

8. Conclusion

In this study The non-linearity and the residual strain of the tether is investigated. A new numerical simulation model is built, and a numerical simulation is conducted in the case of the strong tension.

The results of the numerical simulation are different, since the residuals strain has an effect. In the nonlinear residual strain model the end-mass's velocity is decelerated, since a part of the kinetic energy is lost.

In conclusion If the tethers deployments suddenly stop in the short length and the large tension is generated in the tether, it is important to consider the tether's residual strain.

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