

Getting started



疲劳耐久性仿真

UM 软件入门系列教程

(05)

四川同算科技有限公司 译

2021年3月

本教程介绍使用**UM Durability**模块进行构件疲劳耐久性仿真的基本方法和 流程。

请读者在学习本课程之前务必先学习两个基础课程。其一为《UM软件入门 系列教程01:多体系统动力学仿真》,熟悉UM软件的基本操作,如:新建模型, 创建几何图形、刚体、铰和力元。其二为《UM软件入门系列教程04: 刚柔耦合 动力学仿真》,熟悉导入外部弹性体的方法及多刚体系统与柔性体耦合的实现过 程。

在本课程中,我们将通过一个简单的电机振动平台例子介绍UM软件里应力 载荷谱和疲劳耐久性分析的一般流程和步骤。

我们将直接运行一个准备好的模型,进行动力学计算,然后将结果用于应力 载荷谱分析和疲劳寿命预测,在预测疲劳寿命时采用经典的S-N曲线方法。

请先运行UM Input或UM Simulation程序,选择菜单Help | About,在弹出窗口查看UM Durability一栏是否为 "+"标记,若显示为 "-",则请重新申请试用或购买正版许可。



版权和商标

本教程仅供读者参考,不同的版本其界面可能有个别不同之处,我们会不定 期进行修订。对于本文档中可能出现的任何错误,我们不承担任何责任或义务。

版权所有© 2021 Computational Mechanics Ltd.

俄罗斯计算力学有限公司保留所有权利。

联系方式

最新版的UM软件和相应的用户手册下载地址:

<u>http://www.universalmechanism.com/en/pages/index.php?id=3</u>. 若无法访问,请点击: <u>http://www.umlab.ru/en/pages/index.php?id=3</u>. 在使用过程中,读者如有任何报错、疑问和建议,请发送邮件至:

um@universalmechanism.com

UM总部

Computational Mechanics Ltd.

Vostochnaya str. 2-14, Glinischevo, Bryansk region, 241525, Russia

Phone, fax: +7 4832 568637

www.universalmechanism.com www.umlab.ru

UM中国

四川同算科技有限公司

四川省眉山市彭山区蔡山西路2号伟业广场1911室

办公电话: 028-38520556

公司网站: <u>www.tongsuan.cn</u>

电子邮件: <u>um@tongsuan.cn</u>





微信公众号

QQ 交流群

1.	模块功	能简介	.1
2.	柔性平	台模型	.3
2.1	模型	简介	.3
2.2	工作	流程	.3
2.3	动力	学计算	.4
2.4	应力	载荷谱分析	.8
	2.4.1	载荷工况描述	.9
	2.4.2	初始化 Sensor 节点组	15
	2.4.3	设置应力载荷谱评估参数	17
	2.4.4	保存项目	18
	2.4.5	计算应力载荷时程	19
	2.4.6	应力载荷时程分析结果	20
2.5	疲劳	耐久性分析	25
	2.5.1	设置疲劳耐久性分析方法	25
	2.5.2	选择控制区域	27
	2.5.3	疲劳耐久性分析	35
	2.5.4	结果分析	35





1. 模块功能简介

UM Durability 模块是专业的疲劳耐久性 CAE 分析工具,它基于 UM FEM 刚柔耦合动力学计算的结果进行应力载荷谱分析和疲劳寿命预测。其中,柔性体 通过外部有限元软件导入(目前支持 ANSYS 和 MSC.NASTRAN),刚柔耦合系 统的动力学计算和疲劳后处理都在 UM 软件里完成。

首先,采用模态综合法将构件的柔性特性(包括模态振型和应力张量)从有限元软件导入 UM,构成所需的刚柔耦合动力系统。其次,在 UM 里设置好一个或多个仿真工况,计算得到一系列有限元节点的应力时程数据。最后,根据材料的疲劳强度特性进行疲劳寿命预测。

疲劳耐久性分析有如下三个关键输入:

- 应力载荷数据:节点应力时程;
- 材料数据:材料在不同应力水平的循环载荷作用下的反应;
- 疲劳耐久性分析方法。

由于从有限元软件导入 UM 的柔性体模型包含完整的单元和节点信息,根据模态综合法理论可以直接求得节点在任意时刻的位移和应力。只要选取足够的、 合理的有限阶模态,就能快速地获得比较精确的响应。

在计算柔性体的弹性变形时采用模态叠加的方法,即可以通过一组模态振型 的线性组合得到最终结果。显然,只需要乘以适当的系数,就能将这种方法拓展 到应力的计算。这种系数,又称模态坐标,可以用来表征柔性体的瞬时应力状态。 试想,在动力学计算的每一步,对每一个有限元节点都执行模态叠加计算,那么 就可以获得整个时间历程上的节点位移和应力曲线。

使用 UM FEM 模块进行动力学计算时可以自动保存所有的模态坐标时程。 UM Durability 利用模态坐标时程数据和完整的节点信息(模态文件),可以快速获得每个节点的应力时程。然后,采用雨流计数法统计应力循环次数,最后根据 S-N 曲线等方法评估寿命。

仿真流程如图 1.1 所示。











Getting Started

2. 柔性平台模型

教程《UM 软件入门教程: 刚柔耦合动力学仿真》详细介绍了使用 UM 软件 建立刚柔耦合系统模型的基本方法和步骤,这里不再赘述。

请读者从本地目录找到本例疲劳耐久性分析的动力学模型{UM Data}\ SAMPLES\Durability\Vibrostand。

备注:本例中的有限元模型与前述刚柔耦合分析模型略有不同,由于网格尺寸不同,因此单元和节点数目不同。

2.1 模型简介

研究对象是一个置放电机的柔性平台,如图 2.1 所示。研究目标是柔性平台的应力、应力幅和疲劳寿命。

柔性平台模型包含 4749 个节点,4544 个壳单元,在有限元软件里选取 4 个 界面节点,提取 24 阶静模态和 10 阶固有模态,经正则转换剔除 6 阶刚体模态后, 得到 28 阶自由模态,导入 UM 软件中,通过弹簧和阻尼器力元将平台与地面、 平台与电机连接起来。



图 2.1 电机-柔性平台模型

2.2 工作流程

Universal Mechanism 9

由图 1.1 所知,我们需要利用准备好的刚柔耦合模型进行多个工况的动力学 仿真计算,并储存相应数据用于之后的应力载荷谱分析和疲劳寿命预测。

3





2.3 动力学计算

运行 UM Simulation 仿真程序,加载{UM Data}\SAMPLES\Durability\ Vibrostand 模型。

备注:如果模型不能正常打开,请尝试从{UM Data}\SAMPLES\Flex\Vibrostand 目录下复制 input.dat 文件至{UM Data}\SAMPLES\Durability\Vibrostand 目录, 替换原有文件。

该模型已经定义好了电机工作的三个状态:加速、稳定工作和制动,电机转 子角速度时程曲线如图 2.2 所示,工况参数见表 2-1。



图 2.2 转子角速度 表 2-1 模型参数

参数符号	备注	参数值
nu	电机转子的额定转速(r.p.m)	1620
omega	电机转子的额定角速度(rad/s)	169.6
tstart	启动时间(s)	0.5
tspeeding_up	加速时间(s)	2
tworking	稳定工作时间(s)	3
tbraking	制动时间(s)	4

下面,我们进行一个指定工况的动力学计算。

- 选择菜单File | Load configuration,读取已经配置好的工况参数文件 Vibrostand-configuration.icf。
- 2. 点击,打开仿真控制界面。
- 3. 在Solver页面,勾选Computation of Jacobian。





Object simu	lation inspector							
Solver	Identifiers	Initial condition	ns Object variables	1	KVA	Information	FE subsystems	Tools
Simulation pr	ocess parameters	Solver options	Type of coordinates for l	odies	PP: Optio	ons		
Solver BDF ABM Park Gear 2 Park Park		ype of solution) Null space metho Range space me	od (NSM) thod (RSM)					
Time Step size for Error toleran Delay to r Keep syst Computat	animation and data ice real time simulation tem matrix decomp tion of Jacobian diagonal Jacobian	a storage 0.001 1E-8						
			图 2.	3			X	ж

4. 切换到Identifiers页面,从List of identifiers下拉菜单中选择 Electricmotor电机子系统,按图 2.5检查参数值,如不同,请修改。

XV	A	Info	rmation	FE subsystems	Tools
Solv	er	Identif	ìers	Initial conditions	Object variables
List of identifi	ers Identifi	er control			
~ D	= ale				
	- <u>^</u>	prostand			
Whole list	`	vibrostar	nd ostand		
Name	Ex	Platf	orm		
beamlength	1	Elect	tricmotor		
widthbeams	helflov 0.:				
WidthShelf	0.4				
CXX	1.(
0.00					
CYY	1.1		X	图 2.4	
	/ibrostan	d.Electricmotor	X	图 2.4	
thole list	//ibrostan	d.Electricmotor	X	图 2.4	
Cyy hole list	L.t //ibrostan	d.Electricmotor	Comment	图 2.4	
Cyy	L.t //ibrostan Expression 1.000000E	d.Electricmotor Value	Comment Lateral stiffr	图 2.4	
hole list	1.1 //ibrostan Expression 1.000000E- 1.000000E-	d.Electricmotor	Comment Lateral stiffr Longitudinal	E 2.4	notor
hole list	1.1 //ibrostan Expression 1.0000000E 1.000000E	d.Electricmotor Value	Comment Lateral stiffr Longitudinal Lateral dissig	ES 2.4	iotar or
hole list	1.1 k/ibrostan Expression 1.0000000E- 1.0000000E- 1000 1000	d.Electricmotor Value	Comment Lateral stiffr Longitudinal Lateral dissip Longitudinal	ES 2.4 mess of mount element of electricmotor stiffness of mount element of electricmotor nation of mount element of electricmotor dissipation of mount element of electric	iotor or cmotor
hole list hole list stifflateral stifflongitudinal disslongitudinal u	1.1 k/ibrostan Expression 1.0000000E- 1.0000000E- 1000 1000 1620	d.Electricmotor Value	Comment Lateral stiffr Longitudinal Lateral dissip Longitudinal Nominal ang	ES 2.4 tess of mount element of electricmotor stiffness of mount element of electricmotor ation of mount element of electricmotor dissipation of mount element of electric ular velocity of the rotor, revolutions p	iotor or cmotor er minute (r.p.m.)
thole list lame Stifflateral Stifflongitudinal disslateral disslongitudinal u mega	1.1 kibrostan Expression 1.000000E- 1.000 1000 1000 1620 nu*2*pi/60	d.Electricmotor Value + 169.646	Comment Lateral stiffr Longitudinal Lateral dissip Longitudinal Nominal ang Nominal ang	ES 2.4 tess of mount element of electricmotor stiffness of mount element of electricmotor bation of mount element of electric dissipation of mount element of electric ular velocity of the rotor, revolutions p ular velocity of the rotor, rad/s	iotor or cmotor er minute (r.p.m.)
hole list hole list Stifflateral Stifflongitudinal disslateral disslongitudinal u mega start	1.1 kibrostan Expression 1.000000E- 1.000 1000 1000 1620 nu*2*pi/60 0.5	Value + 169.646	Comment Lateral stiffr Longitudinal Lateral dissip Longitudinal Nominal ang Nominal ang Time before	ES 2.4 tess of mount element of electricmotor stiffness of mount element of electricmotor ation of mount element of electric ular velocity of the rotor, revolutions p ular velocity of the rotor, rad/s speeding up, s	iotor or cmotor er minute (r.p.m.)
Cyy Thole list Iame Stifflateral Stifflongitudinal disslateral disslongitudinal u mega start speeding_up	1.1 kibrostan Expression 1.000000E- 1.000 1000 1000 1620 nu*2*pi/60 0.5 2	d.Electricmotor Value + 169.646	Comment Lateral stiffr Longitudinal Lateral dissip Longitudinal Nominal ang Nominal ang Time before Time of spec	ES 2.4 tess of mount element of electricmotor stiffness of mount element of electricmotor bation of mount element of electric ular velocity of the rotor, revolutions p ular velocity of the rotor, rad/s speeding up, s eding up mode, s	iotor or cmotor er minute (r.p.m.)

图 2.5

5. 选择页面FEM subsystems | Simulation | Options, 勾选Store values of modal coordinates,并设置保存类型为File,缺省以柔性子系统的名字 命名并存放于模型目录,如图 2.6所示。





Object sin	nulation ir	ispecto	r					
Solver	Iden	tifiers	Initial conditions	Object variables	XVA	Information	FE subsystems	Tools
Subsyste	m: Platf	orm						
General	Simulation	Image	Solution					
Options	Damping							
General Gravi Switc Calculat	ity h off all flex ion of initial iodal coordir	cible mod condition nates	les					
Storing Store Destina Mer File: c	e values of r ation mory : \users \pub	nodal coo	ordinates nents\um software la	D\universal mechanism\8	File \samples\du	urability\vibrostand	Platform.imc <u>q</u>	a 🗶 🖟



6. 在FEM subsystems | Simulation | Damping页面,设置结构阻尼,如图 2.7所示。

	r Iden	tifiers	Initial cor	nditions	Object variał	oles	XVA	Information	FE subsystems	Т
Subsyste	em: Platfo	orm								
General	Simulation	Image	Solution							
Options	Damping									
Dampin	g									
✓ Inte	rnal dissipati	on								
-		011								
Type o	of definition									
Line	ear model									
	mping ratio fr	or each n	ode							
0.00	inping rado it	or coorn	looic							
linear	model									
D=i	aC+bM									
	0000				n	h. D				
a: 10.1	0003				- K	D: U				
Dampin	ig ratio for ea	ach mode	2							
-Dampin Calc	ig ratio for ea ulate	ach mode								
Dampin Calci	g ratio for e a ulate Frequency	r (Hz)	2			Dampi	ng rati	io		
Dampin Calco	ng ratio for ea ulate Frequency 15.1013	ach mode 7 (Hz)				Dampi O	ng rati	0		
Dampin Calco N 1 2	g ratio for ex ulate Frequency 15.1013 42.0629	ach mode 7 (Hz)	2			Dampi O O	ng rati	0		

- 7. 切换到Solver页面,点击Integration,执行计算,计算过程中会自动生成两个文件(Platform.imc和Platform.tmc),并存放于模型目录。
- 8. 待计算完毕,点击**确定 | Interrupt**,当提示是否覆盖原有模态坐标文件 时,选择**是(Y)**。







图 2.8

9. 最后,点击Close,关闭仿真控制界面。

备注:请勿关闭模型,否则进行疲劳耐久性分析时需要手动指定柔性体文件。

Universal Mechanism 9





2.4 应力载荷谱分析

选择主菜单 Tools | Durability wizard, 打开应力载荷谱和疲劳耐久性分析向 导界面, 如图 2.9 所示。

X Stress loading	and durability analysis wizard	
General Stress loa	ding analysis Durability analysis	
Project: Stress loa	ding and durability analysis project	
Creation data:	2020/3/2 15:05:38	
Last save:	2020/3/2 15:05:38	
Close		
	图 2.9	
ΙΖ.		
R		





2.4.1 载荷工况描述

加载模态坐标时程

本例电机的三种工作状态,可以从先前的一次仿真结果中提取出来。

- 1. 定位到Stress loading analysis | Source data | Loading regimes页面。

组织 🔹 新建文	件夹							0
🚺 下载	*	名称	修改日期		类型		t	小
三 桌面	-	B coMasha	2021 /2/1	E1#9				
💹 最近访问的位	置	Oliviesnes Diatform	2021/3/1	生 <u>朝</u> 一… 6 星期	 、 又 件 关 			
<u>)</u> 9	1	Platform.tmc	2021/2/2	星期一	UM Doc	ument.		1
퉳 x64	0			added that in				-
库								
📑 视频	=							
📓 图片								
📑 文档								
🔒 迅雷下载								
👌 音乐								
📕 计算机								
💼 m:s								•
	+14-57				- 4-1 4	Circles Cl	- /*	_
	又14-4(1)	i): Platform.tmc		• [M	odal coord	inates fil	ie (".tm	
		<u></u>	3 2.10		打开(0) ▼]	取消	at a
Stress loading and	durability	r analysis wizard	3 2.10		汀开(O) ↓	;	取消	
Stress loading and	d durability	analysis wizard	3 2.10		汀开(O) ┃▼		取消	
Stress loading and	d durability analysis Du	r analysis wizard rrability analysis ngs Cakulation Results	3 2.10		57开(Ο) ↓		取消	×
Stress loading and Control Control Co	d durability analysis Du roups Settii Modal co	r analysis wizard rrability analysis ngs Calculation Results pordinate file(g), (*.tmc)	3 2.10		□7开(Ο) ▼		取消	
Stress loading and The stress loading a Source data Sensor gr Data source type Object Loading regime	d durability analysis Du roups Setti Modal cc es Realizat	r analysis wizard rrability analysis ngs Calculation Results pordinate file(s), (*.tmc) ions Limits	3 2.10		77开(O)		取消	
Stress loading and eneral Stress loading a Source data Sensor gr Data source type Object Loading regime + • • •	d durability analysis Du roups Setti Modal cc es Realizat	rability analysis rability analysis ngs Calculation Results pordinate file(s), (*.tmc) jons Limits	3 2.10		77开(0)		取消	
Stress loading and eneral Stress loading a Source data Sensor gr Data source type Object Loading regime + • • • • • • • • • • • • • • • • • • •	d durability analysis Du roups Setti Modal cc es Realizat	rability analysis rability analysis ngs Calculation Results oordinate file(s), (*,tmc) ions Limits rectory	3 2.10		汀开(0) ↓	File nar	取消	
Stress loading and eneral Stress loading a Source data Sensor gr Data source type Object Loading regime + • • • • • • • • • • • • • • • • • • •	d durability analysis Du roups Settii Modal cc es Realizat Di orm.tmc] C ::	rability analysis rability analysis ngs Calculation Results oordinate file(s), (*,tmc) ions Limits rectory :Users/Public/Documents/UM Softwar	2.10	PLES\Durab	可开(O)	File nar	取消 回 me m.tmc	
Stress loading and eneral Stress loading a Source data Sensor gr Data source type Object Loading regime + • • • • • • • • • • • • • • • • • • •	d durability roups Settin Modal cc es Realizat prm.tmc] C: crm.tmc] C:	rability analysis vizard rability analysis ngs Calculation Results ordinate file(s), (*, tmc) ions Limits rectory :Users'Public/Documents/UM Softwar :Users'	E 2.10 re Labijuniversal Mechanism (8)SAM re Labijuniversal Mechanism (8)SAM	PLES\Durab	可开(O)	File nar	取消 me m.tmc m.tmc	
Stress loading and eneral Stress loading a Source data Sensor gr Data source type Object Loading regime + • • • • • • • • • • • • • • • • • • •	d durability analysis Du moups Setti Modal cc es Realizat Di crm.tmc] C: crm.tmc] C: crm.tmc] C:	r analysis wizard rability analysis rability analysis rgs Calculation Results oordinate file(s), (*tmc) ions Limits rectory ;Users;Public/Documents;UM Softwar ;Users;Public/Documents;UM Softw	E Lab Universal Mechanism \8\SAM re Lab Universal Mechanism \8\SAM re Lab Universal Mechanism \8\SAM	PLES \Durab	ility(Vibrostanc ility(Vibrostanc ility(Vibrostanc ility(Vibrostanc	File nar Platforr Platforr Platforr	取消 me m.tmc m.tmc m.tmc	
Stress loading and eneral Stress loading a Source data Sensor gr Data source type Object Loading regime + I I I I Load block[Platfo 2 Load block[Platfo 3 Load block[Platfo	d durability analysis Du moups Setti Modal cc es Realizat prm.tmc] C: crm.tmc] C:	r analysis wizard rability analysis ngs Calculation Results ordinate file(s), (*tmc) tions Limits rectory Waers Public (Documents JUM Softwar Waers (Public (Documents JUM Softwar	E Lab Universal Mechanism (8)SAM re Lab Universal Mechanism (8)SAM re Lab Universal Mechanism (8)SAM	PLES \Durab	可开(O)	File narr	取消 me m.tmc m.tmc m.tmc	
Stress loading and eneral Stress loading a Source data Sensor gr Data source type Object Loading regime + I I I Cad block[Platfo 2 Load block[Platfo 3 Load block[Platfo	d durability analysis Du moups Setti Modal cc es Realizat prm.tmc] C: crm.tmc] C:	r analysis wizard rability analysis ngs Calculation Results ordinate file(s), (*tmc) tions Limits rectory Waers Public (Documents WM Softwar Waers Public (Documents WM Softwar Waers Public (Documents WM Softwar	E Lab Universal Mechanism (8) SAM re Lab Universal Mechanism (8) SAM re Lab Universal Mechanism (8) SAM	PLES\Durab PLES\Durab	可开(O)	File nam	取消 me m.tmc m.tmc m.tmc	
Stress loading and Stress loading a Source data Sensor gr Data source type Object Loading regime + I I I Cadblock [Platfo 2 Load block [Platfo 3 Load block [Platfo	d durability analysis Du roups Setti Modal cc es Realizat prm.tmc] C: crm.tmc] C: crm.tmc] C:	r analysis wizard rability analysis ngs Calculation Results sordinate file(s), (*tmc) tions Limits rectory Waers Public (Documents JUM Softwar Waers (Public (Documents JUM Softwar Waers (Public (Documents JUM Softwar	E Lab\Universal Mechanism\B\SAM re Lab\Universal Mechanism\B\SAM re Lab\Universal Mechanism\B\SAM	1 PLES/Durab	可开(O)	File naro A Pletform	取消 me m.tmc m.tmc m.tmc	
Stress loading and Stress loading a Source data Sensor gr Data source type Object Loading regime + I I I I Load block[Platfo 2 Load block[Platfo 3 Load block[Platfo	d durability analysis Du roups Setti Modal cc es Realizat prm.tmc] C: crm.tmc] C: crm.tmc] C:	r analysis wizard rability analysis ngs Calculation Results sordinate file(s), (*tmc) tions Limits rectory Livers/Public/Documents/LM Softwar Livers/Public/Documents/LM Softwar Livers/Public/Documents/LM Softwar	E Lab\Universal Mechanism\B\SAM re Lab\Universal Mechanism\B\SAM re Lab\Universal Mechanism\B\SAM	9 LES Durab	可开(O) 「 ility(Wbrostane ility(Wbrostane	File narrow File N	取消 me m.tmc m.tmc	
Stress loading and Provide the sense of the	d durability analysis Du moups Setti Modal cc es Realizat prm.tmc] C: crm.tmc] C: crm.tmc] C:	r analysis wizard rability analysis ngs Calculation Results sordinate file(s), (*tmc) tions Limits rectory Waers Public (Pocuments JUM Softward Waers (Public (Pocuments JUM Softward) Waers (Public (Pocuments JUM Softward)	E Lab\Universal Mechanism\B\SAM re Lab\Universal Mechanism\B\SAM re Lab\Universal Mechanism\B\SAM	PLESDurab	可开(O) 「 間try(Vbrostanc 間try(Vbrostanc	File nar	取消 n me m.tmc m.tmc m.tmc	
Stress loading and Stress loading a Source data Sensor gr Data source type Object Loading regime + I I I I Load block[Platfo 2 Load block[Platfo 3 Load block[Platfo	d durability analysis Du roups Setti Modal cc es Realizat prm.tmc] C: crm.tmc] C: crm.tmc] C:	r analysis wizard rability analysis ngs Calculation Results sordinate file(s), (*tmc) tions Limits rectory Livers/Public/Documents/LM Softwar Livers/Public/Documents/LM Softwar Livers/Public/Documents/LM Softwar	E Lab\Universal Mechanism\8\SAM re Lab\Universal Mechanism\8\SAM re Lab\Universal Mechanism\8\SAM	PLES/Durab	ility(Wbrostanc ility(Wbrostanc ility(Wbrostanc	File nar A Pletforn A Pletforn	取消 ne me m.tmc m.tmc m.tmc	





设置工况区间

在当前页面,点击**右键**,选择 Load values from file,可以从已有文件读取 工况名称(位于模型下的 LoadCasesCaptions.lcc),也可以在 Caption 一列的单元 格中直接修改。







模型可视化

只要成功加载了一个模态坐标时程数据,就可以在 Stress loading analysis | Source data | Object 页面查看柔性体模型及相关数据,可设置如图 2.13 显示 (Full 模式,不显示所有节点)。







绘制时程曲线

我们以第 3773 号和 259 号节点为例绘制其等效应力时程曲线,如图 2.15 所示。

- 1. 切换到Stress loading analysis | Source data | Realization页面。
- 2. 在左侧选择Unsigned von Mises by principle stresses选项。
- 3. 在右侧Sensor number处输入3773,点击Calculate(或敲回车键)。
- 4. 打开一个绘图窗口,拖动¹图标至绘图窗口然后放开,随即显示了节点 3773的Mises等效应力时程曲线。
- 5. 用同样的方法,在同一个绘图窗口中显示节点259的Mises等效应力时程曲线。

Stress loading and durability analysis wizard	
Ceneral Stress loading analysis Durability analysis	
Source data Senser groups Sottings Coloridation Description	
Date and Sensor groups Setungs Calculation Results	
Data source type Modal coordinate file(s), (*.tmc)	
Object Loading regimes Realizations Limits	
Select stress combination OMax. Abs. principle stress Max. principle stress OMax. principle stress	You can evaluate and plot stress time histories at any sense for the defined load case. Select stress type, load case and node number and drag th marked field to graphical windows.
Unsigned you Mises by principle stresses	Load case:
O Unsigned von Mises by normal and shear stresses	1. Speeding up $$
O X normal stress	Sensor number:
O Y normal stress	3773 Calculate
◯ Z normal stress	Eo plot the stress time history drag over this field
○ X-Y shear stress	to a graphic window
○ Y-Z shear stress	
○ Z-X shear stress	
Stress time history evaluation algorithm	
mean values from finite elements	
◯ finite element with maximum RMS	
Close	

图 2.14







图 2.15

从图 2.15 可以清楚地看出,柔性平台节点的应力时程与先前定义的电机工作工况一致,开机 0.5s,加速过程 2s,稳定工作 3s,制动过程 4s。





定义工况的时间区间

切换到 Stress loading analysis | Source data | Limits 页面,通过右键菜单 Load values from file 选择三个工况的时间区间配置文件 Time intervals.int(位于 模型目录),也可以在每个单元格手动输入数值,最终如图 2.18 所示。



图 2.18

14

Universal Mechanism 9

Getting Started





2.4.2 初始化 Sensor 节点组

本例模型的有限元单元数目并不算多,因此可选取所有的节点来进行应力载 荷谱分析(全部作为 Sensor)。

1. 定位到**Stress loading analysis** | **Sensor groups**页面,缺省选取了所有的 有限元节点,如图 2.19所示。

 ✗ Stress loading and durability ➡ □ □ □ □ □ ☑ □ 	analysis wizard		
General Stress loading analysis Dur	rability analysis		
Source data Sensor groups Settin	ngs Calculation Results		
+ 主 🛍			
Group caption	Sensor count	Stress combination	
All FEM nodes	4740	S1MOD	
	Add sensor group	Ins	
	Group properties		
	Remove sensor group	Del	
	图 2 10		

- 2. 选中All FEM nodes, 点**右键**,选择Group properties (或直接双击All FEM nodes),弹出Sensor节点组属性窗口。
- 3. 在Node list页面,显示了所有的节点。

Properties N	ode list Stress com	bination		
				Add
Group node lis	st			
Node 1	Node 14	Node 27	Node 40	Delete
Node 2	Node 15	Node 28	Node 41	
Node 3	Node 16	Node 29	Node 42	
Node 4	Node 17	Node 30	Node 43	
Node 5	Node 18	Node 31	Node 44	
Node 6	Node 19	Node 32	Node 45	
Node 7	Node 20	Node 33	Node 46	
Node 8	Node 21	Node 34	Node 47	
Node 9	Node 22	Node 35	Node 48	
Node 10	Node 23	Node 36	Node 49	
Node 11	Node 24	Node 37	Node 50	
Node 12	Node 25	Node 38	Node 51	
Node 13	Node 26	Node 39	Node 52	
•			•	

图 2.20





4. 在Stress combination页面,选择Unsigned von Mises by principle

Properties Node list Suess combination	
Select stress combination	
Max. Abs. principle stress	
Min. principle stress	
 Unsigned von Mises by principle stresses 	
Unsigned Misec by normal and shear stresses	
X normal	
Y normal A normal	
© X-Y shear	
🔘 Y-Z shear	
Z-X shear	
Stress time history evaluation algorithm	
employee mean values from finite elements	
finite element with maximum RMS	
	Adjust for all node groups

5. 设置Stress time history evaluation algorithm 为 mean values from finite elements。

备注:通常情况一个有限元节点同时属于多个单元,因此这个选项决定其节点应 力的计算方式。

6. 点击OK,将以上设置应用于所有节点。





2.4.3 设置应力载荷谱评估参数

在 Stress loading analysis | Settings 页面,分别设置 General 和 Additional 如图 2.22 和图 2.23 所示。

eneral Stress loading analysis Durability anal	ysis	
ource data Sensor groups Settings Calcul	ation Results	
General Additional		
Filtration		
Loading process filtering	Set filter parameters	
Schematization		
Schematization algorithm	Rainflow method \sim	
Distribution calculation method	Autodetection of a stress interval width $\qquad \qquad \lor$	
Stress interval width (MPa)	0.00001	
Interval count	32 🖍	
Ignore cycles with amplitudes less than hal	If a stress interval width	
Stress calculation	0	
0		
Close		
Close	图 2.22	
Close Stress loading and durability analysis	图 2.22 wizard	
Close Stress loading and durability analysis	图 2.22 wizard	
Close Stress loading and durability analysis Close Stress loading and durability analysis Close Stress loading analysis Durability analysis Close Clos	图 2.22 wizard	
Close Stress loading and durability analysis Close Stress loading and durability analysis Close Stress loading analysis Close Close Stress loading analysis Close	图 2.22 wizard	
Close Stress loading and durability analysis Close Close Stress loading and durability analysis Close Stress loading analysis Durability ana Source data Sensor groups Settings Clacu Closessol Additional	图 2.22 wizard	
Close Stress loading and durability analysis Press loading analysis Durability ana Stress loading analysis Durability ana Source data Sensor groups Settings Calcu General Additional Central Frequence evaluation	图 2.22 wizard	
Close Stress loading and durability analysis Ress loading and durability analysis Ress loading analysis Durability ana Source data Sensor groups Settings Calcu General Additional Central frequence evaluation M By count of intersections with average value	图 2.22 wizard lysis lation Results	
Close Stress loading and durability analysis Close Clo	wizard Ivsis Iation Results	

图 2.23





2.4.4 保存项目

点击按钮础将分析项目保存在当前模型目录。

		1.1			
组织▼ 新建文件夹					•
🚖 收藏夹	各 称	修改日期	类型		大小
🚺 下载	🔒 GOMeshes	2021/3/1 星期一	文件夹		
📃 桌面	🎍 Platform	2021/2/26 星期	文件夹		
💹 最近访问的位置					
) 9	E				
퉳 x64					
库					
🛃 视频					
■ 图片					
🖹 文档					
🔒 迅雷下载					
👌 音乐	1991 				_
~~~~~	, , , , , ,		<b>屋友(5)</b>	ED2	ж
$\langle \rangle$	图 2.24	1 · · ·			





### 2.4.5 计算应力载荷时程

- 1. 定位到Stress loading analysis | Calculation页面。
- 2. 点击Calculate,开始计算。点击 ^爹 按钮可以显示所有的工况进度,整个

计算过程大约持续5-10分钟。

3. 待计算完毕,点击确定。







2.4.6 应力载荷时程分析结果

- 1. 定位到Stress loading analysis | Results | Sensor list页面。
- 2. 在Load case列表选择Combined stressed block (缺省即是)。
- 3. 点击Maximal amplitude (MPa)两次,使得节点以最大应力幅降序排列。

由图 2.26 可见,节点 258、3771、3772、3773 和 3770 具有相对较大的应 力幅。

-										
eral Stress l	oading analysis	Durability a	nalysis							
urce data Se	ensor groups Se	ttings Cal	culation Res	ults						
ž										
ingle sensor	Distributions Vis	sualization	Sensor list							
oad case	Combined	d stressload	block		$\sim$					
Node number	Sensor group	Stress	Min. str	Max. stress (MPa)	Mean s	RMS of	Centr	Comment	Minim	Maximal amplitude
258	All FEM nodes	SEQV1	0.480	157.503	(none)	(none)	(none)	Standard I	0.000	78.491
3771	All FEM nodes	SEQV1	0.216	150.594	(none)	(none)	(none)	Standard I	0.000	75.189
3772	All FEM nodes	SEQV1	0.182	150.555	(none)	(none)	(none)	Standard I	0.000	75.165
3773	All FEM nodes	SEQV1	0.164	149.094	(none)	(none)	(none)	Standard I	0.000	74.465
3770	All FEM nodes	SEQV1	0.450	149.063	(none)	(none)	(none)	Standard I	0.000	74.306
3774	All FEM nodes	SEQV1	0.238	146.322	(none)	(none)	(none)	Standard I	0.000	73.023
3769	All FEM nodes	SEQV1	0.292	145.917	(none)	(none)	(none)	Standard I	0.000	72.813
4315	All FEM nodes	SEQV1	0.347	144.934	(none)	(none)	(none)	Standard I	0.000	72.293
4346	All FEM nodes	SEQV1	0.309	144.858	(none)	(none)	(none)	Standard I	0.000	72.162
4284	All FEM nodes	SEQV1	0.299	143.508	(none)	(none)	(none)	Standard I	0.000	71.604
4377	All FEM nodes	SEQV1	0.629	143.206	(none)	(none)	(none)	Standard I	0.000	71.206
3775	All FEM nodes	SEQV1	0.179	142.241	(none)	(none)	(none)	Standard I	0.000	71.031
3768	All FEM nodes	SEQV1	0.495	141.144	(none)	(none)	(none)	Standard I	0.000	70.325
4253	All FEM nodes	SEQV1	0.343	140.864	(none)	(none)	(none)	Standard I	0.000	70.261
4408	All FEM nodes	SEQV1	0.298	139.925	(none)	(none)	(none)	Standard I	0.000	69.814
4314	All FEM nodes	SEQV1	0.303	139.479	(none)	(none)	(none)	Standard I	0.000	69.588
4345	All FEM nodes	SEQV1	0.250	139.327	(none)	(none)	(none)	Standard I	0.000	69.290
4283	All FEM nodes	SEQV1	0.376	138.246	(none)	(none)	(none)	Standard I	0.000	68.897
3776	All FEM nodes	SEQV1	0.164	136.962	(none)	(none)	(none)	Standard I	0.000	68.399
1376	All FEM nodes	SEQV1	0.540	137.613	(none)	(none)	(none)	Standard I	0.000	68.316
4222	All FEM nodes	SEQV1	0.386	136.951	(none)	(none)	(none)	Standard I	0.000	68.221
542	All FEM nodes	SEQV1	0.335	136.734	(none)	(none)	(none)	Standard I	0.000	68.025
1757	All EEM pades	CEOV1	0.260	100 700	(0000)	(0000)				

图 2.26

- 重复以上三步,依次找到三个工况的最大应力幅的主要节点。
   Speeding up: 258、3770、3771、3769、3772
   Stable work: 258、542、3769、3768、3770
   Braking: 258、3771、3772、3773、3770
- 5. 定位到Stress loading analysis | Results | Visualization页面。
- 6. 选择Load case 为Combined stressload block。
- 7. 设置Select data for visualization 为Maximal values of stress cycle amplitudes (Mpa),如图 2.27所示。
- 8. 点击**Show**,打开一个新的动画窗口,并显示综合工况下的应力幅分布云图。





X Stress loading and durability analysis	s wizard
🛏 🗄 🖽	
General Stress loading analysis Durability an	nalysis
Source data Sensor groups Settings Calo	culation Results
- BARE	
Single sensor Distributions Visualization	Sensor list
Load case: Combined s	tressload block ~ Show
Select data for visualization: Maximal val	ues of stress cycle amplitudes (MPa) V





- 9. 点击动画窗口工具栏上的 ° 图标,用于显示用户选择的节点。
- 10. 在动画窗口点右键,选择菜单Select FE nodes。
- 11. 在弹出窗口选择by index模式,在Node number处输入258,依次点击 Search, Add,将其添加到右侧节点列表,并自动在动画窗口中以绿色 高亮显示。





List of flexible subsystems		Nodes in group: 5
platform	•	Nodes selected: 5
Search node Search node by index Node number: 3773 Node coordinates:	<mark>f</mark> z	List of nodes: ✓ 1. Node 258 (-0.200, -0.200, 0.060) ✓ 2. Node 3770 (-0.200, -0.038, 0.060 ✓ 3. Node 3771 (-0.200, -0.025, 0.060 ✓ 4. Node 3772 (-0.200, -0.013, 0.060 ✓ 5. Node 3773 (-0.200, 0.000, 0.060
-0.200 0.000 0. elected node I: 3773 X: -0.200 Y: 0.000 Z: 0.060 Search Add Clear Clo	.060	

图 2.29

12. 以同样的方法添加节点3770、3771、3772和3773,如图 2.30所示。



13. 点击Close关闭节点选择窗口。

备注:如果直接点击 Close 出现报错情况,请退出报错界面,先 Clear,再 Close。





14. 定位到Stress loading analysis | Results | Single sensor页面,设置Node number为258,如图 2.31所示。可见,最大应力幅发生在加速和制动工况。

88.	8													
eral Stress loadi	ng analysis Dur	ability analys	is											
urce data Senso	r groups Settin	gs Calculat	ion Results											
權														
Single sensor Dist	ributions Visual	ization Sen	sor list											
Node number:	258	1 🖉 🖬												
Load case	Sensor group	Stress t	Min. str	Max. str	Mean str	RMS of stre	Ce	Comment	Minimal	Maximal am	Minimum	Maximum	Cycle count	
Speeding up	All FEM nodes	SEQV1	0.521	157.503	35.001	42.074	(n	Standar	0.003	78.491	1.347	81.087	69.000	
Stable work	All FEM nodes	SEQV1	4.547	137.680	82.754	39.793	(n	Standar	55.125	66.566	64.154	73.265	145.500	
Braking	All FEM nodes	SEQV1	0.480	153.884	26.824	36.635	(n	Standar	0.000	76.702	1.288	81.906	114.000	
Combined stres	All FEM nodes	SEQV1	0.480	157.503	0.000	0.000	0	Standar	0.000	78.491	1.288	81.906	(none)	

图 2.31

15. 定位到Stress loading analysis | Results | Distributions页面,可查看节点 平均应力和应力幅的双参数分布表。

neral Stress lo	ading analysis D	urability analysis										
ource data Ser	nsor groups Sett	ings Calculation	Results									
94E												
Single sensor	Distributions Visu	alization Senso	r list									
Load case:	1. Speedin	g up	~	Sensor number	1 1/1	🧭 🖪 🚺						
Two-parameter	distribution Amp	olitude values dis	tribution Mean	values distributio	n							
	Amplitude value	N₽	1	2	3	4	5	6	7	8	9	
Mean values		Interval width (	[0.0010.222]	[0.2220.444]	[0.4440.665]	[0.6650.886]	[0.8861.108]	[1.1081.329]	[1.3291.551]	[1.5511.772]	[1.772	1
N9	Interval width (	Value (MPa)	0.111	0.333	0.554	0.776	0.997	1.219	1.440	1.661	1.883	
1	[0.1510.375]	0.263	4.615	0	0	0	0	0	0	0	0	
2	[0.3750.599]	0.487	0	1.538	0	0	0	0	0	0	0	
3	[0.5990.822]	0.710	12.308	5.385	3.846	0	0	0	0	0	0	
4	[0.8221.046]	0.934	0	0	0.769	6.154	0	0	0	0	0	
5	[1.0461.270]	1.158	0	0	0	0	1.538	0	0	0	0	
6	[1.2701.494]	1.382	0	0	0	0	1.538	3.077	0	0	0	
7	[1.4941.718]	1.606	0	0	0	0	0	1.538	1.538	0	0	
8	[1.7181.942]	1.830	0	0	0	0	0	0	0	1.538	0	
9	[1.9422.166]	2.054	0	0	0	0	0	0	0	1.538	0.769	
10	[2.1662.390]	2.278	0	0	0	0	0	0	0	0	0	
11	[2.3902.614]	2.502	0	0	0	0	0	0	0	0	0	
12	[2.6142.837]	2.725	0	0	0	0	0	0	0	0	0	
13	[2.8373.061]	2.949	0	0	0	0	0	0	0	0	0	
14	[3.0613.285]	3.173	0	0	0	0	0	0	0	0	0	
15	[3.2853.509]	3.397	0	0	0	0	0	0	0	0	0	

图 2.32





### 16. 点击 适按钮,可查看三维直方图。







# 2.5 疲劳耐久性分析

## 2.5.1 设置疲劳耐久性分析方法

1. 定位到**Durability analysis** | **Evaluation method**页面,设置**Evaluation method**为**S-N method**,如图 2.34所示。

al Stress loading analysis Durability analysi	is	
uation method Control areas Evaluation F	Results	_
luation method S-N method	· · · · · · · · · · · · · · · · · · ·	/
ess loading description Durability evaluation	parameters	
educed amplitude distribution		
ean stress correction method	(ignore) V	
wer-range amplitude value (MPa)	0 🔲 🗌 Set as a part of fatigue strength	
Part of fatigue strength	0 [[]]	
lative parts of the operational regimes per the	e selected lifetime unit	_
etime unit	User-defined lifetime unit	
etime unit caption	work day	
Set rela	tive parts of the operational regimes per the selected lifetime unit	
		_

- 图 2.34
- 2. 在Stress loading description页面,设置Mean stress correction method 为ignore,即本例忽略平均应力对疲劳损伤的贡献。
- 3. 设置Lower-range amplitude value为0, 表示所有的载荷循环都要计入耐 久性分析。
- 4. 设置Life time unit为User-defined lifetime unit, 自定义寿命周期单位为 work day。
- 点击Set relative parts of the operational regimes per the selected lifetime unit,设置每work day(对应用户自定义的寿命周期单位)各个工 况的重复次数。假设电机每天工作8小时,开关机各1次,因此设置
   Speeding up和Braking工况重复次数为1,Stable work工况重复次数为 10670(8*60*60/2.699)。





No	Load case	Repetition count
1	Speeding up	1
2	Stable work	10670
3	Braking	1



- 6. 切换到**Durability evaluation parameters**页面。
- 7. 设置Probability of no-failure为95%,即正常开机工作率为95%。
- 8. 设置Reduction coefficient为310,表示平均每年工作310天。
- 9. 勾选Calculate safety factor,设置设计使用寿命Design life time value为 10年。

Evaluation method	Control areas Evaluation	Results	
Stress loading desc Probability of no-f	ription Durability evaluation	n parameters	
1	•	99.9	
Parameters Fatigue damage a	ccumulation model	Linear damage accumulation model (Palmgren-Miner rule)	
Calculate safet	y factor ime (vear)	10	





#### 2.5.2 选择控制区域

我们需要根据应力载荷谱分析的结果,结合柔性平台的结构特征来选取疲劳 耐久性分析的控制区域,即不必分析所有节点。

从前述结果分析可知,最大应力幅出现在 Speeding up 和 Braking 两个工况, 相应的节点主要位于平台上层顶板靠近电机转子一侧边缘(3770,3771,3772, 3773)。同时,顶板与支撑梁的连接部位(258,542)也有较大的应力幅,由于 折角处存在应力集中,因此对疲劳寿命影响较大。

有限元分析可能很好地评估顶板主体的应力状态,但是对于连接区域则可能 会有些误差。因此,对于顶板主体,可以直接采用局部弹性应力进行疲劳分析; 而对于连接区域,则需要修正,即采用名义应力。

下面,我们来定义柔性平台的控制区域和材料疲劳强度特性。

1. 定位到Durability analysis | Control areas页面,如图 2.37所示。

E	valuation m	ethod Cont	rol areas	Evaluation Results					
_	+	Î							
1	Node gr	Node co	Material	Sf of the material	Total Sf reduction coe	Sf of the group	Variation coefficien	Safety Sf value	Safe

图 2.37





roperties Node list						
Caption	Top plate					
Material		Add new material				
oading type	Bend	Bend				
S-N curve description						
S-N curve type Model No5	- Piecewise linear approximation	*	Plot S-N curve			
Sf0: Fatigue strength of a	specimen: R=-1 (MPa)	0.001 📖				
Kf: Total fatigue strength	reduction coefficient	1 📃	Evaluation			
Sf: Fatigue strength of th	e group: R=-1 (MPa)	0.001 🗐	]			
SE: Coefficient of variation	n of the fatigue strength of the group	0 🔳	Arbitrary 👻			
Nc1: Base cycle count (millio	ons of cycles)	0.001 🔝				
B1: Slope of S-N curve firs	t line 10	000 🔳				
B2: Slope of S-N curve sec	ond line 10	000 🔲				
Residual/temperature stress	es (MPa)		3			
Residual/temperature stress	ies (MPa)	1				
Residual/temperature stress Ok Cancel	es (MPa)					

 $\checkmark$ 





- 3. 切换到Node list页面。
- 4. 通过右键菜单Load node list from file载入事先准备好的节点列表(根据 应力载荷分析而确定的区域)。

				Add
Concentration in the				Auu
Group node list	4190			Delete
Node 3769 Node	4283		0	
Node 3771 Node	4252			
Node 3772 Node	4344 Add a	ll nodes		
Node 3774 Node	4313			
Node 3775 Node	4251 Delete	e selected nodes	Del	
Node 3776 Node	4220 Delete	e all nodes		
Node 3770 Node	4312			
Node 3778 Node	4250 Load	node list from file		
Node 4408 Node	4280 Save	node list to file		
Node 4377 Node	1439			
Node 4346 Node 4	4375			
Node 4284 Node	4343			
Node 4253 Node	4311			
Node 4222 Node	4279			
Node 4191 Node .	5/6/			
Node 4376				
Node 4345				
Node 4314				
Ok Ca	ncel 图 2			
Node 4221 Ok Ca	ncel 图 2	2.39		×
Node 4221 Ok Ca Load node list	ncel 图 2 MPLES + Durability + Vibrostand		寛泰 Vibrostanc	× م ب
Node 4221 Ok Ca Load node list	ncel 图 2 MPLES + Durability + Vibrostand	2.39 • • • • • •	寛奈 Vibrostanc 圓☷	× م 9 آ
Node 4221 Ok Ca Load node list 通《9 + SA 组织 * 新建文件夹 读 收藏夹	ncel 图 2 MPLES , Durability , Vibrostand 名称	2.39 • • • • • 4	健康 Vibrostance 間Ⅲ 类型	× ~ 、 、 、 、 、 、 、 、 、 、 、 、 、
Node 4221 Ok Ca Load node list ↓ 《 9 → SA 组织 ▼ 新建文件夹 ★ 收藏夹 ↓ 下载	ncel MPLES → Durability → Vibrostand 名称 J GOMeshes	2.39 • • • • • • • • • • • •	<i>寵奈 Vibrostanc</i> 順Ⅲ 类型 、文件夹	× へ 、 、 、 、 、 、 、 、 、 、 、 、 、
Node 4221           Ok         Ca           Load node list            ●         ●         ●           ▲         ●         ●         >           ▲         坂蔵夫         ●         下载         ●           ■         桌面         ●         ●         ●	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform	2.39 ◆ 4→ 4 修改日期 2021/3/1星期一 2021/2/26星期	2度家 Vibrostance 目前 美型 · 文件夹 文件夹	× の マーロ マーマ 大小
Node 4221           Ok         Ca           Load node list         ●           ●         ●         ●           ▲         ●         ●           ▲         ●         ●           ▲         ●         ●           ▲         ●         ●           ●         ●         ●           ▲         ●         ●           ●         ●         ●           ●         ●         ●           ●         ●         ●           ●         ●         ●           ●         ●         ●	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform List of connection nodes.nls	<ul> <li>39</li> <li></li></ul>	變蒙 Vibrostance 題語 类型 · 文件夹 文件夹 UM Docum	×
Node 4221         Ok       Ca         Load node list       ●         ●       ●       ●         ▲       ●       ●         ▲       ●       ●       ●         ▲       ●       ●       ●         ▲       ●       ●       ●         ●       ●       ●       ●         ▲       ●       ●       ●         ●       ●       ●       ●         ●       ●       ●       ●         ●       ●       ●       ●         ●       ●       ●       ●         ●       ●       ●       ●         ●       ●       ●       ●         ●       ●       ●       ●         ●       ●       ●       ●         ●       ●       ●       ●         ●       ●       ●       ●	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform List of connection nodes.nls Utits of top plate nodes .nls	<ul> <li>.39</li> <li>、 、 、 、 、 、 、 、 、 、 、 、 、 、 、 、 、 、 、</li></ul>	2度家 Vibrostance 業型 ・文件夹 文件夹 UM Docum UM Docum	・ ・ で で 大小 ent. L 1 ent. L 1
Node 4221         Ok       Ca         Load node list         ●       ●       ●       > SA         组织 ▼       新建文件夹       ●       ●       SA         週訳 ▼       新建文件夹       ●       ●       ●       ●       ●         ●       ●       ●       ●       ●       ●       ●       ●         ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ● </td <td>ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform Itist of connection nodes.nls Itist of top plate nodes .nls</td> <td><ul> <li>◆ ◆ ◆ ▲</li> <li>修改日期</li> <li>2021/3/1 星期一</li> <li>2021/2/26 星期</li> <li>2016/8/24 星期</li> <li>2016/9/29 星期</li> </ul></td> <td><i>壁家 Vibrostano</i> 順三 英型 、文件夹 文件夹 UM Docum UM Docum</td> <td>✓ ♪ ✓ □ ② 大小 ent. L 1 ent. L 1</td>	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform Itist of connection nodes.nls Itist of top plate nodes .nls	<ul> <li>◆ ◆ ◆ ▲</li> <li>修改日期</li> <li>2021/3/1 星期一</li> <li>2021/2/26 星期</li> <li>2016/8/24 星期</li> <li>2016/9/29 星期</li> </ul>	<i>壁家 Vibrostano</i> 順三 英型 、文件夹 文件夹 UM Docum UM Docum	✓ ♪ ✓ □ ② 大小 ent. L 1 ent. L 1
Node 4221         Ok       Ca         Load node list       ●         ▲       ●       ●       ●         組织       新建文件夹       ●       ●         ▲       收藏夹       ●       ●       ●         ●       ●       ●       ●       ●       ●         ●       ●       ●       ●       ●       ●       ●         ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●       ●	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform List of connection nodes.nls List of top plate nodes .nls		變要 Vibrostance 業型 · 文件夹 文件夹 UM Docum UM Docum	・ ・ で 大小 ent. L 1 ent. L 1
Ok       Ca         Ok       Ca         Load node list       ●         1       ●       ●         49 > SA       ●         419        新建文件夹         ★ 收藏夹       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●         ●       ●	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform List of connection nodes.nls List of top plate nodes .nls		變要 Vibrostance 業型 · 文件夹 文件夹 UM Docum UM Docum	・ ・ で 大小 ent. L 1 ent. L 1
Ok       Ca         Ok       Ca         Load node list       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1       ●       ●         1	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform List of connection nodes.nls List of top plate nodes .nls		變要 Vibrostance 業型 · 文件夹 文件夹 UM Docum UM Docum	<ul> <li>×</li> <li>・</li> <li>・</li></ul>
Node 4221         Ok       Ca         Load node list          Load node list <td< td=""><td>ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform Ist of connection nodes.nls Ist of top plate nodes .nls</td><td>39</td><td><i>健要 Vibrostanc</i></td><td>▼ □ 0 ▼ □ 0 大小 ent. L 1 ent. L 1</td></td<>	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform Ist of connection nodes.nls Ist of top plate nodes .nls	39	<i>健要 Vibrostanc</i>	▼ □ 0 ▼ □ 0 大小 ent. L 1 ent. L 1
Node 4221         Ok       Ca         Load node list          Load node list          小 位 学 9 → SA          组织 ▼       新建文件夹         ★ 收藏夹          ● 安街	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform Itist of connection nodes.nls Itist of top plate nodes .nls		變要 Vibrostance 谜面 类型 · 文件夹 文件夹 UM Docum UM Docum	✓ ♪ ✓ ♪ 大小 ent. L 1 ent. L 1
Node 4221         Ok       Ca         Load node list          Load node list          小 位 学 9 → SA          组织 ▼       新建文件夹         ★ 收藏夹          ● 下载          ● 子 数          ● 安街          ● 取用下载	ncel MPLES → Durability → Vibrostand 名称 GOMeshes Platform Itist of connection nodes.nls Itist of top plate nodes .nls		總要 Vibrostance 穩証 类型 · 文件夹 文件夹 UM Docum UM Docum	✓
Node 4221         Ok       Ca         Load node list          Load node list          山田田田田田田田田田田田田田田田田田田田田田田田田田田田田田田田田田田田田	ncel MPLES > Durability > Vibrostand 名称 GOMeshes Platform 喻 List of connection nodes.nls w List of top plate nodes .nls		2度家 Vibrostance 度正 英型 ・文件夹 文件夹 UM Docum UM Docum	・ ・ 一 、 で 、 大小 ent. L 1 ent. L 1
Node 4221         Ok       Ca         Load node list          Lage with the list          Load node list	ncel MPLES + Durability + Vibrostand 名称 GOMeshes Platform ① List of connection nodes.nls ① List of top plate nodes .nls	2.39 ★ 4 至 至 1 章 1 章 1 章 1 章 1 章 1 章 1 章 1 章 1 章	鍵家 Vibrostance 選び 業型 、文件来 文件来 UM Docum UM Docum	✓ ● ● ● ● ● ● ● ● ● ● ● ● ● ● ● ● ● ● ●

图 2.40





5. 回到**Properties**页面,点击**Add new material**按钮,根据表 2-2来定义材 料参数。

	静强度参数	
Sy	屈服强度(Mpa)	305
Su	极限强度(Mpa)	440
	典型材料的疲劳强度物	寺性
Sf	疲劳强度(定循环载荷作用N0次数	210
	下失效概率为50%)	
N0	基准循环数(S-N曲线拐点)	1E+007
b1	S-N曲线第一段斜率	0.125
b2	S-N曲线第二段斜率	0.020

表 2-2

6. 弹出材料参数窗口,切换到Strength页面,设置屈服强度为305Mpa,极限强度为440Mpa。

Mechanical Anisotropic	Thermal	Strength	S-N F	atigue: Tension	S-N Fatigue: Bending	S-N Fatigue: Torsion
Parameter	Val	ue	Units	description.		
Yield Stress Tension		305	MPa			
Yield Stress Shear		157	MPa			
Stress 02		448	MPa			
Ultimate Stress		440	MPa			
Breaking Elongation		0.25	%			
Breaking Narrowing		0.65	%			





7. 切换到S-N Fatigue: Bending页面,从下拉菜单选择Model No 5-Piecewise linear approximation类型的S-N曲线。

S-N curve type       Model No 5 - Piecewise linear approximation       Plot S-N curve         Model No 1 - Straight line in logarithmic scales       SAI: Stress ampliti, Model No 2 - Piecewise linear approximation       B1: Slope of S-N, Model No 3 - Hyperbolic approximation         B1: Slope of S-N, Model No 3 - Hyperbolic approximation       Model No 4 - According to RD-50-694-90       Nc1: Fatigue trans         B2: Slope of S-N curve: second line       0.05 ml         Sf: Endurance limit amplitude of specimen: R=-1 (MPa)       0 ml         Standart error of fatigue strength (MPa)       0 ml         Cycle asymmetry sensitivity coefficient       0 ml	Mechanical Anisotropic   Thermal   Strength   S-N Fatigue:	Tension S-N Fa	tigue: Bending	S-N Fatigue: T	orsion 🔄 🕨
Model No 1 - Straight line in logarithmic scales         SAI: Stress amplity         Model No 2 - Piecewise linear approximation         B1:       Slope of S-N         Model No 4 - According to RD-50-694-90         Nc1: Fatigue trans       Model No 5 - Piecewise linear approximation         B2:       Slope of S-N curve: second line       0.05 mill         Sf:       Endurance limit amplitude of specimen: R=-1 (MPa)       0 mill         Standart error of fatigue strength (MPa)       0 mill         Cycle asymmetry sensitivity coefficient       0 mill	S-N curve type Model No 5 - Piecewise linear approximat	ion 🔻	Plot S-N cu	rve	
B2:       Slope of S-N curve: second line       0.05 [m]         Sf:       Endurance limit amplitude of specimen: R=-1 (MPa)       0 [m]         Standart error of fatigue strength (MPa)       0 [m]         Cycle asymmetry sensitivity coefficient       0 [m]	Model No 1 - Straight line in logarithmic so SAI: Stress amplit. Model No 2 - Piecewise linear approximation B1: Slope of S-N Model No 3 - Hyperbolic approximation Model No 4 - According to RD-50-694-90 Nc1: Fatigue trans Model No 5 - Piecewise linear approximati	ales on			
Sf:       Endurance limit amplitude of specimen: R=-1 (MPa)       0 [m]         Standart error of fatigue strength (MPa)       0 [m]         Cycle asymmetry sensitivity coefficient       0 [m]	B2: Slope of S-N curve: second line	0.05 🔲			
Standart error of fatigue strength (MPa)     0 Im       Cycle asymmetry sensitivity coefficient     0 Im	Sf: Endurance limit amplitude of specimen: R=-1 (MPa)	0 🔲			
Cycle asymmetry sensitivity coefficient 0 🔟	Standart error of fatigue strength (MPa)	0 🔜			
	Cycle asymmetry sensitivity coefficient	0 🔲			
	Sf: Endurance limit amplitude of specimen: R=-1 (MPa) Standart error of fatigue strength (MPa) Cycle asymmetry sensitivity coefficient	0			
				OK	Cancel

8. 设置S-N曲线参数如图 2.43所示(SAI=210*10e7^0.125=1574.7778Mpa)。

1echanical Anisotropic Thermal Strength S-N Fatigue	: Tension S-N Fatig	ue: Bending	S-N Fatigue: To	orsion
S-N curve type Model No 5 - Piecewise linear approxim	ation 🔹	Plot S-N cu	rve	
SAI: Stress amplitude intercept (MPa)	1574.777:			
31: Slope of S-N curve: first line	0.125 📕			
Ic1: Fatigue transition point (millions of cycles)	10 📕			
2: Slope of S-N curve: second line	0.02 📠			
f: Endurance limit amplitude of specimen: R=-1 (MPa)	210 📠			
Standart error of fatigue strength (MPa)	0 📠			
Cycle asymmetry sensitivity coefficient	0 🔜			
Adjust to all			OK	Cance

9. 依次点击Adjust to all和OK,分配给本组所有节点,保存到材料库。

备注:如果出现报错,忽略即可。





10. 回到顶板的Group properties界面,设置Coefficient of variation of the fatigue strength of the group为0.1。

Caption	Top plate			
caption				
Material	[Material_1		•	Add new material
oading type	Bend		•	Edit material
S-N curve description				
S-N curve type Model M	No5 - Piecewise linear approximation		-	Plot S-N curve
Sf0: Fatigue strength o	of a specimen: R=-1 (MPa)	210		
Kf: Total fatigue strength reduction coefficient 1				Evaluation
Sf: Fatigue strength o				
SE: Coefficient of vari	ation of the fatigue strength of the group	0.1		Arbitrary *
Nc1: Base cycle count (	millions of cycles)	10		
B1: Slope of S-N curve	first line	0.125 📃		
B2: Slope of S-N curve	second line	0.02 🔲		
Safety factor of the fati	aue strenath			
/alue 1	Safety factor value is used for fa evaluation which is used in durab	tigue strengt lity prediction	n i algoi	rithm
Residual/temperature st	resses (MPa)	0		
		700		
Ok Cano	cel			

 点击Evaluation,定义Total fatigue strength reduction coefficient,如图
 2.45所示,其中Effective stress concentration factor为1,表示不考虑应 力集中,直接采用局部弹性应力。

Result	1.17647			
- Effectiv	e stress concentration factor	Arbitrary 🔫	1	
- Surface	hardening factor	Arbitrary 👻	1	6
- Size fac	tor	Arbitrary 👻	1	6
- Surface	finish factor	Rough surface after rolling (0.85) 🔻	0.85	5
L Multiplie	er	1 🔜		

图 2.45

12. 连续点击两个OK,保存控制区域Top plate的材料数据。





- 13. 添加一个新的控制区域,命名为Connections。
- 14. 选择与Top Plate相同的材料类型,并设置参数如图 2.46所示。

Properties Node list						
Caption	Connections					
Material	[Material_1		Add new material			
Loading type	Bend		-	Edit material		
S-N curve description	97		120			
S-N curve type Model No	-N curve type Model No5 - Piecewise linear approximation					
Sf0: Fatigue strength of	a specimen: R=-1 (MPa)	210				
Kf: Total fatigue strength reduction coefficient				Evaluation		
Sf: Fatigue strength of	the group: R=-1 (MPa)	210				
SE: Coefficient of variat	ion of the fatigue strength of the group	0		Arbitrary		
Nc1: Base cycle count (mi	llions of cycles)	10				
B1: Slope of S-N curve fi	rst line	0.125 🔟				
B2: Slope of S-N curve se	econd line	0.05 📠				
Safety factor of the fatigu	e strength					
Value 1	Safety factor value is used for fa evaluation which is used in durab	itigue strengt ility prediction	algor	rithm		
Residual/temperature stre	sses (MPa)	0				
Ok Cance						

图 2.46

备注:英文手册中显示此处 B2 为 0.02,我们这里设置为 0.05。

15. 点击Evaluation,按图 2.47设置疲劳强度修正系数(考虑应力集中、表面处理、粗糙度、尺寸大小等效应)。

Result 2.75				
Effective stress concentration factor	Arbitrary	*	2.75	
- Surface hardening factor	Arbitrary	•	1	
– Size factor	Arbitrary		1	
– Surface finish factor	Polish (1.0)	•	1	
Multiplier	1 🔟			

图 2.47





# 16. 在Node list页面,通过右键菜单加载连接区域节点Connections node list.nls。

Properties N	Node list					
	0-					Add
Group node l	list					Delete
Node 3727	Node 2186	Node 3815	Node 131	Node 322	Node 4736	Delete
lode 3789	Node 2192	Node 3805	Node 293	Node 323	Node 4735	
lode 3790	Node 2195	Node 2207	Node 294	Node 259	Node 4737	
lode 3791	Node 2198	Node 2210	Node 297	Node 565	Node 4733	
lode 3792	Node 2177	Node 2213	Node 295	Node 542	Node 4734	
lode 3793	Node 3795	Node 2219	Node 296	Node 315	Node 3757	
lode 3794	Node 3800	Node 2222				
lode 3796	Node 2189	Node 3809	Add all	nodes		
lode 3797	Node 3803	Node 2216		and the second		
lode 3798	Node 2201	Node 2225	Delete	selected node	s Del	
lode 3799	Node 2204	Node 2231	Delete	all nodes		
lode 3801	Node 3804	Node 2237	Derete	annoucs		
lode 3802	Node 3806	Node 2234	Load a	ada list from f		
lode 2086	Node 3807	Node 2228	Load n	oue list from i	lie	
lode 2014	Node 3808	Node 2240	Save n	ode list to file		
lode 2013	Node 3810	Node 2246	1100E 309	11008 4740	NODE 4729	
lode 2156	Node 3811	Node 2243	Node 310	Node 4749	Node 4732	
lode 2159	Node 3816	Node 2122	Node 308	Node 4748	Node 4731	
lode 2162	Node 3817	Node 2428	Node 311	Node 4744	Node 4730	
lode 2165	Node 3818	Node 2378	Node 313	Node 4742	Node 4728	
lode 2171	Node 3788	Node 3819	Node 312	Node 4743		
lode 2174	Node 3812	Node 2168	Node 318	Node 4741		
lode 2180	Node 3813	Node 156	Node 320	Node 4739		
lode 2183	Node 3814	Node 179	Node 321	Node 4738		
٠ [					۲	
OF	Cancel	с С				
UK						
			图 2.48			
		$\langle / / \rangle$				
点击이	K。	XX				





### 2.5.3 疲劳耐久性分析

- 1. 定位到**Durability analysis** | Evaluation页面。
- 2. 点击Calculate,整个计算过程不到5秒钟。

# 2.5.4 结果分析

- 1. 定位到Durability analysis | Results | Node list页面。
- 选择Load case为Combined stressload block,根据使用寿命排序,如图 2.49所示。

eral Stress Id	ading analysis	Durability analys	515							
aluation metho	d Control area	as Evaluation	Results							
de list Sena	rate node Stre	ess loading Visi	alization							
du case:	Combine	d stressload bloc	ж		× 😰 🗉	9				
lode number	Control area	Stress type	Maximal am	Equivalent	Cycle count	Damage pe	Durability(	Life-time (y	Safety fact	^
42	Connections	SEQV1	68.025	54.669	1.55267E006	0.000	5150.600	16.615	1.661	
758	Connections	SEQV1	56.467	39.279	1.55267E006	0.000	3.83278E006	12363.800	1236.380	
65	Connections	SEQV1	48.410	38.729	1.55267E006	0.000	5.07986E006	16386.700	1638.670	
59	Connections	SEQV1	43.234	34.296	1.55267E006	0.000	5.77889E007	186416.000	18641.600	
749	Connections	SEQV1	46.847	33.468	1.55267E006	0.000	9.41873E007	303830.000	30383.000	
23	Connections	SEQV1	41.032	32.376	1.55267E006	0.000	1.82887E008	589959.000	58995.900	
22	Connections	SEQV1	36.247	28.542	1.55267E006	0.000	2.27483E009	7.33815E006	733815.000	
21	Connections	SEQV1	31.574	24.800	1.55267E006	0.000	3.78012E010	1.21939E008	1.21939E007	
20	Connections	SEQV1	28.652	22.473	1.55267E006	0.000	2.71405E011	8.75499E008	8.75499E007	
748	Connections	SEQV1	32.945	22.448	1.55267E006	0.000	2.77281E011	8.94455E008	8.94455E007	
788	Connections	SEQV1	42.702	22.034	1.54734E006	0.000	4.04051E011	1.30339E009	1.30339E008	
378	Connections	SEQV1	43.401	21.465	1.54733E006	0.000	6.81441E011	2.1982E009	2.1982E008	
19	Connections	SEQV1	26.518	20.784	1.55267E006	0.000	1.29445E012	4.17563E009	4.17563E008	
.56	Connections	SEQV1	26.815	19.639	1.54732E006	0.000	4.03396E012	1.30128E010	1.30128E009	
18	Connections	SEQV1	24.855	19.473	1.55267E006	0.000	4.76366E012	1.53666E010	1.53666E009	
17	Connections	SEQV1	23.514	18.407	1.55267E006	0.000	1.46834E013	4.73658E010	4.73658E009	
819	Connections	SEQV1	34.635	17.580	1.54734E006	0.000	3.69787E013	1.19286E011	1.19286E010	
16	Connections	SEQV1	22.404	17.505	1.55267E006	0.000	4.01138E013	1.294E011	1.294E010	
727	Connections	SEQV1	19.374	16.780	1.55268E006	0.000	9.34997E013	3.01612E011	3.01612E010	
15	Connections	SEQV1	21.467	16.726	1.55267E006	0.000	9.97636E013	3.21818E011	3.21818E010	
013	Connections	SEQV1	22.995	16.655	1.54732E006	0.000	1.08925E014	3.51372E011	3.51372E010	
747	Connections	SEQV1	26.280	16.630	1.55267E006	0.000	1.11881E014	3.60906E011	3.60906E010	
789	Connections	SEQV1	18.275	16.091	1.55268E006	0.000	2.16232E014	6.97522E011	6.97522E010	~

由图 2.49 看出,最危险的区域位于节点 542 处,其寿命为 16.615 年(能工 作 5150 天),符合设计标准,该构件满足工况需求。





定位到Durability analysis | Results | Separate node页面,选择节点542, 3. 由图 2.50可知,节点542最危险的工况为Stable work。

stress loadin	ig and durabi	lity analysis w	izard - C:\User	s\Public\Docu	ments\UM So	ftware Lab\Ur	iversal Mecha	anism\8\SAMP	LES\D 🗖 🔍	
88.	1									
ieral Stress lo	ading analysis	Durability analy	sis							
aluation metho	d Control area	s Evaluation	Results							
ŧ										
lode list Sepa	rate node Stre	ess loading Visu	alization							
iode number:	542	<u></u>								
Load case	542 Control area	Stress type	Maximal am	Equivalent	Cycle count	Damage pe	Durability(	Life-time (y	Safety fact	
ode number: .oad case Speeding up	Control area	Stress type SEQV1	Maximal am 68.025	Equivalent 57.043	Cycle count 69.000	Damage pe 0.000	Durability( 4.95205E007	Life-time (y 159744.000	Safety fact no data	
Load case Speeding up Stable work	Control area Connections Connections	Stress type SEQV1 SEQV1	Maximal am 68.025 58.702	Equivalent 57.043 54.669	Cycle count 69.000 1.55249E006	Damage pe 0.000 0.000	Durability( 4.95205E007 5151.430	Life-time (y 159744.000 16.618	Safety fact no data no data	
ode number: .oad case Speeding up Stable work Braking	542 Control area Connections Connections Connections	Stress type SEQV1 SEQV1 SEQV1 SEQV1	Maximal am 68.025 58.702 65.063	Equivalent 57.043 54.669 54.009	Cycle count 69.000 1.55249E006 114.000	Damage pe 0.000 0.000 0.000	Durability( 4.95205E007 5151.430 8.9433E007	Life-time (y 159744.000 16.618 288494.000	Safety fact no data no data no data	
Load case Speeding up Stable work Braking Combined s	542 Control area Connections Connections Connections Connections	Stress type SEQV1 SEQV1 SEQV1 SEQV1 SEQV1	Maximal am 68.025 58.702 65.063 68.025	Equivalent 57.043 54.669 54.009 54.669	Cycle count 69.000 1.55249E006 114.000 1.55267E006	Damage pe 0.000 0.000 0.000 0.000	Durability( 4.95205E007 5151.430 8.9433E007 5150.600	Life-time (y 159744.000 16.618 288494.000 16.615	Safety fact no data no data no data 1.661	

图 2.50

定位到Durability analysis | Results |Stress loading页面,输入节点号542。 4.

lode list Ser	parate node Stress loading	Visualization			
.oad case:	Combined stressloar	d block v S	ensor number 542	2 🖬 🖬	
No	Interval width (MPa)	Median stress (MPa)	Probability, %	Cycle count per work day	
1	[5,75E-0005,.2,12582]	1.0629397	0.002222	34,499997	
2	[2, 12582, .4, 25159]	3,1887042	0.000676	10,500001	
3	[4,251596.37735]	5.3144686	0.000676	10,500000	
4	[6.377358.50312]	7,4402331	0.000451	7.000001	
5	[8,50312,.10,6289]	9,5659975	0.000451	7.000001	
6	[10.6289., 12.7546]	11.691762	0.000515	8.000000	
7	[12.754614.8804]	13.817526	0.000129	2.000001	
8	[14.880417.0062]	15.943291	0.000322	5.000000	
9	[17.0062., 19, 1319]	18.069055	0.000129	2.000001	
10	[19.131921.2577]	20.19482	0.000193	2.999999	
11	[21.257723.3835]	22.320584	0.000064	1.000001	
12	[23.383525.5092]	24.446349	0.000193	2.999999	
13	[25.509227.635]	26.572113	0.000064	1.000002	
14	[27.63529.7608]	28.697878	0.000193	2.999999	
15	[29.760831.8865]	30.823642	0.000129	2.000002	
16	[31.886534.0123]	32.949407	0.000322	4.999998	
17	[34.012336.1381]	35.075171	0.000129	2.000000	
18	[36.138138.2638]	37.200935	0.000322	4.999996	
19	[38.263840.3896]	39.3267	0.000064	1.000005	
20	[40.389642.5153]	41.452464	0.000193	3.000000	
21	[42.515344.6411]	43.578229	0.000322	5.000001	
22	[44.641146.7669]	45.703993	0.000258	4.000000	
23	[46.766948.8926]	47.829758	20.616513	320106.030000	

图 2.51





5. 点击 函按钮,可查看直方图。





备注:软件此处有 BUG,多个选项未显示,待以后更正。