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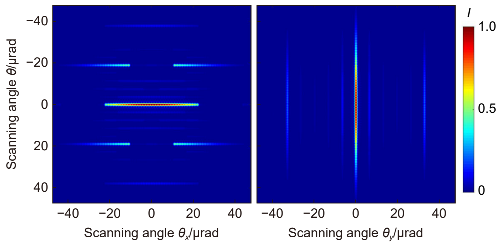
# 甚多孔径光纤激光相控阵的光束扫描特性研究



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**摘要：** 甚多孔径光纤激光阵列是构建大功率、高光束质量、等效光学大口径的新兴技术手段之一，而基于相位精密操控实现阵列激光束的共相，乃至快速、灵活的光束偏转是当前光纤激光相控阵技术面向应用的关键。本文将光学相控扫描技术与光纤激光相干合成系统相结合，研究了甚多孔径光纤激光相控阵的光束扫描特性，通过改变准直激光阵列相邻子孔径间的相位差实现了光束扫描。对比分析了 19、133、703 孔径光纤激光相控阵的远场扫描光束形态分布特征，据此定义并计算了扫描极限范围。该结果为后续开展光纤激光相控阵在长程传输下精确指向控制实验研究提供了理论依据。

**关键词：** 光纤激光相控阵；光束扫描；甚多孔径；相位操控

**中图分类号：** TN820.2　　**文献标志码：** A

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# Research on beam steering of numerous sub-aperture fiber laser phased array

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**Abstract:** Numerous sub-aperture fiber laser array is one of the emerging technologies to build high power, high beam quality and equivalent optical large aperture. Realizing the common phase and even the fast and flexible beam deflection of array laser beam based on the precise phase control is the key to the application of the current fiber laser phased array technology. In this paper, the optical phase-controlled steering technology is combined with the fiber laser coherent combining system, and the beam steering characteristics of the numerous sub-aperture fiber array laser coherent combining systems are studied. The beam steering is realized by changing the phase difference between the adjacent sub-aperture of the collimated laser array. The far-field steering beam pattern

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distribution characteristics of 19, 133 and 703 aperture fiber laser phased arrays are compared and analyzed, and the steering limit range is defined and calculated accordingly. The results provide a theoretical basis for the subsequent experimental research on the precise pointing control of fiber laser phased arrays under long-range transmission.

**Keywords:** fiber laser phased array; beam steering; numerous sub-aperture; phase control

## 1　引　言

光学相控阵 (Optical phase-controlled steering, OPAs) 技术是一种对光学孔径单元的波前相位实施有序、精确调控的技术，能够克服传统机械式波束控制的局限，实现无惯性灵活光束偏转[1-2]，被广泛应用于激光雷达、空间光通信等领域[3-7]。现有的光学相控阵实现途径主要包括液晶相控阵、微机电系统相控阵、硅基相控阵和光纤激光相控阵等[8-13]。光纤激光相控阵作为光纤激光技术[14-15] 与光学相控阵技术结合所产生的一种表现形式，主要以密集排布的光纤准直器阵列作为相控阵的孔径单元，通过操控活塞相位实现相干合成，是突破单路光纤输出功率限制，实现大口径、高质量、高功率激光输出的有效途径[16-18]。如果采用自适应光纤准直器作为孔径单元，还可以实现子孔径的独立倾斜相位操控[19-20]。

当前，光纤激光相控阵技术的主要发展方向之一是通过扩充孔径数目以实现大规模的激光相干合成。2016 年，美国戴顿大学 Vorontsov 团队构建了由三个 7 孔径模块拼接而成的光纤激光相控阵系统[21]，实现了传输距离为 7 km 的激光相干合成。2020 年，国防科技大学周朴团队通过闭环控制实现了 107 单元的光纤激光相干合成[22]。同年，中科院光电技术研究所耿超等人报道了如图 1(a) 所示的 19 孔径光纤激光相控阵[6,23]，实现了传输距离为 2 km 的激光相干合成；正在开展三个 19 孔径基础模块的共形簇拼接与相位操控研究[24]，如图 1(b) 所示。

本文针对甚多孔径光纤激光相控阵技术的发展趋势，提出了借由多个 19 孔径基础模块 (如三十七个) 的簇拼接构建米量级等效口径光纤激光相控阵的设想，如图 1(c) 所示，为研发低成本、轻量化的大口径光学收发系统提供了新的思路。类比于微波相控阵[25]，通过操控更多孔径单元的波前相位，可以释放光学相控阵系统除了相干合成之外更多的能力。据此，将建立等效口径为米量级的光纤激光相控阵发射系统模型，基于光学相控阵理论，利用多孔径的活塞相位调制实现电控光束扫描，对比分析等效口径一定时不同孔径数目对光束扫描特性的影响，研究光束全程高精度二维扫描范围及特征，为光纤激光相控阵在长程传输下的目标精确指向控制和一定范围内的光束快速覆盖提供了重要参考。

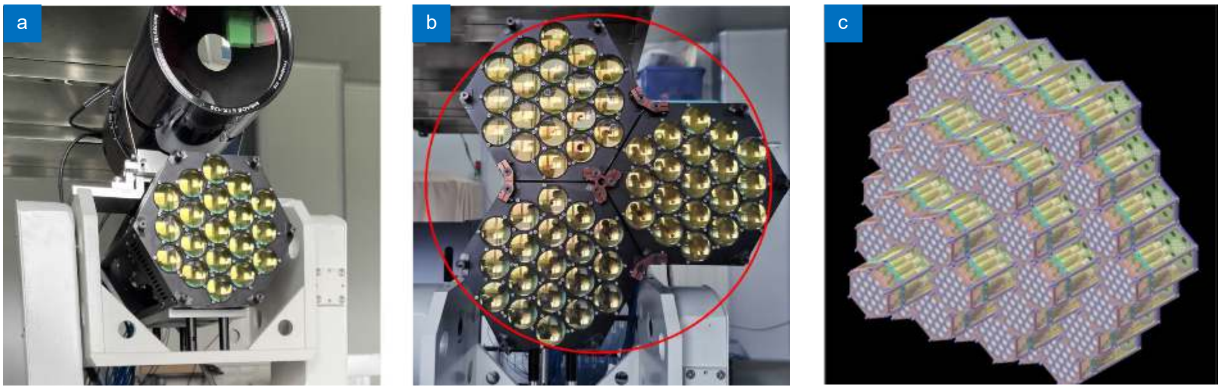

图 1　多孔径光纤激光相控阵。
(a) 19 孔径光纤激光相控阵基础模块；(b) 57 孔径光纤激光相控阵；
(c) 由基础模块构建米级等效口径光纤激光相控阵的构想图 (703 孔径)

Fig. 1　Multi-aperture fiber laser phased array.
(a) 19 apertures fiber laser phased array basic module; (b) 57 apertures fiber laser phased array; (c) Conception of meter-scale equivalent aperture fiber laser phased array from the basic module fiber laser phased array (703 apertures)

## 2　多孔径光纤激光相控扫描理论分析

光纤激光相控阵呈六边形密集排布是目前广为采用的排列方式之一[26-27]。本文以正六边形阵列排布的19孔径光纤激光相控阵为基础单元模块，平面结构模型如图2所示。子孔径直径为$d$，等效口径为$D$，定义沿$x$轴的相邻子孔径间距为$s_x$，沿$y$轴的相邻子孔径间距为$s_y$。

基于光学相控阵原理，采用如图3所示的阶梯状相位折叠模型，通过调整相邻单元间光束出射的活塞相位，可实现在一定范围内的光束扫描。其中，根据光波的周期性可将相邻子孔径间的最大相移量控制在一个波长以内。

对于单孔径出射的归一化高斯光束振幅可表示为

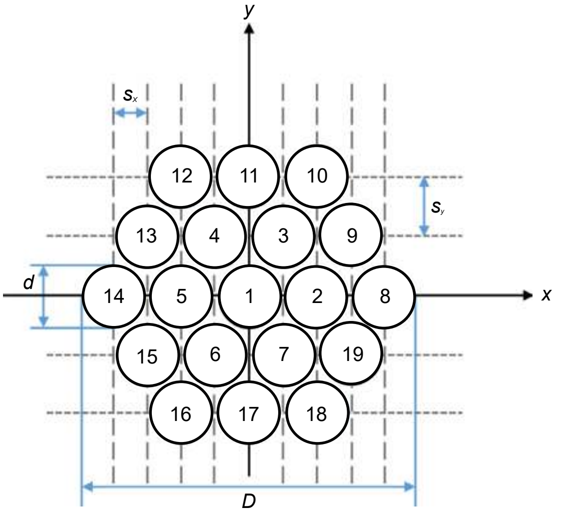

图2　19孔径光纤激光相控阵平面结构图

Fig. 2　Plane structure of 19 apertures fiber laser phased array

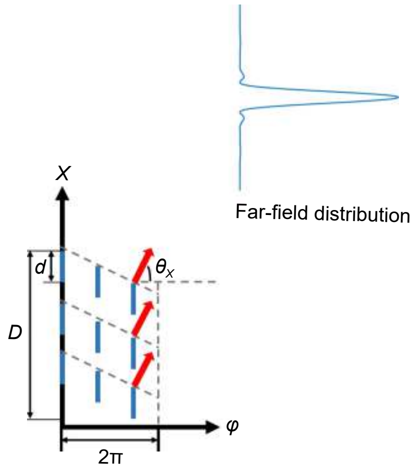

图3　阶梯状相位折叠模型沿 x 轴的光束扫描过程

Fig. 3　Beam steering process of stepped phase folding model along *x*-axis

$$E_0(x,y) = \exp\left(-\frac{x^2+y^2}{\omega_0}\right)C_{\text{circle}}\left(\frac{\sqrt{x^2+y^2}}{d/2}\right). \tag{1}$$

式中：$\omega_0$为子光束束腰半径，$C_{\text{circle}}$为圆域函数。对于多孔径阵列在近场平面的光束出射总光场分布可表示为

$$E(x,y) = \exp\left(-\frac{x^2+y^2}{\omega_0}\right)C_{\text{circle}}\left(\frac{\sqrt{x^2+y^2}}{d/2}\right) * \sum\left[\delta(x_n,y_n)\exp(\mathrm{i}\varphi_n)\right]. \tag{2}$$

式中：*表示卷积运算，$(x_n,y_n)$为第$n$个孔径的位置坐标，$\varphi_n$为第$n$个孔径的相位，其中$n$=1，2，…，$N$。若各个子孔径的相位都相等，则光束平行出射；若对相邻子孔径施加相等的相位差$\Delta\varphi$，则可实现光束偏转，其中相位差$\Delta\varphi = \varphi_n - \varphi_{n-1}$。

出射光在远场形成的光场分布为

$$E(u,v) = \frac{1}{\mathrm{i}\lambda L}\exp\left[\frac{\mathrm{i}k}{2L}\left(u^2+v^2\right)\right] \times \mathcal{F}\{E(x,y)\}_{f_u=\frac{u}{\lambda L},f_v=\frac{v}{\lambda L}}. \tag{3}$$

式中：$\lambda$为激光波长，$L$为光束的传输距离，波矢量$k=2/\pi\lambda$，$\mathcal{F}\{E(x,y)\}$表示关于$x$和$y$的二维傅里叶变换，$f_u = u/\lambda L$，$f_v = u/\lambda L$为远场平面的空间频率。通过调制子孔径的相位$\varphi_n$可得到不同的远场光场分布：

$$\mathcal{F}\{E(x,y)\} = \exp\left(-\frac{u^2+v^2}{\omega_0}\right) * \frac{\mathrm{J}_1\left(\pi d\sqrt{u^2+v^2}/\lambda L\right)}{\pi d\sqrt{u^2+v^2}/\lambda L} \times \mathcal{F}\left\{\sum\delta(x_n,y_n) * \exp(\mathrm{i}\varphi_n)\right\}. \tag{4}$$

对应的归一化远场强度分布为

$$I = \frac{E(u,v)^2}{I_0}. \tag{5}$$

由式(4)可知，六边形排布相控阵扫描模型的远场由两部分组成，一部分是包络因子

$$p = \exp\left(-\frac{u^2+v^2}{\omega_0}\right) * \frac{\mathrm{J}_1\left(\pi d\sqrt{u^2+v^2}/\lambda L\right)}{\pi d\sqrt{u^2+v^2}/\lambda L}.$$

如图4(a)所示，其中$\mathrm{J}_1$是一阶贝塞尔函数；另一部分是网格因子

$$q = \mathcal{F}\left\{\sum\delta(x_n,y_n) * \exp(\mathrm{i}\varphi_n)\right\}.$$

如图4(b)所示。包络因子由相控阵模型的固有参数决定，在整个扫描过程中保持不变，其决定了光束的最大扫描范围及主瓣的峰值能量；网格因子由相控阵子孔径的位置排布和出射光束相位决定，可以通过控制子孔径间的相位差改变网格因子的位置，使主瓣光束的位置发生变化。图4(c)为多个子光束经过相位调控后，在远场干涉形成光束偏转。

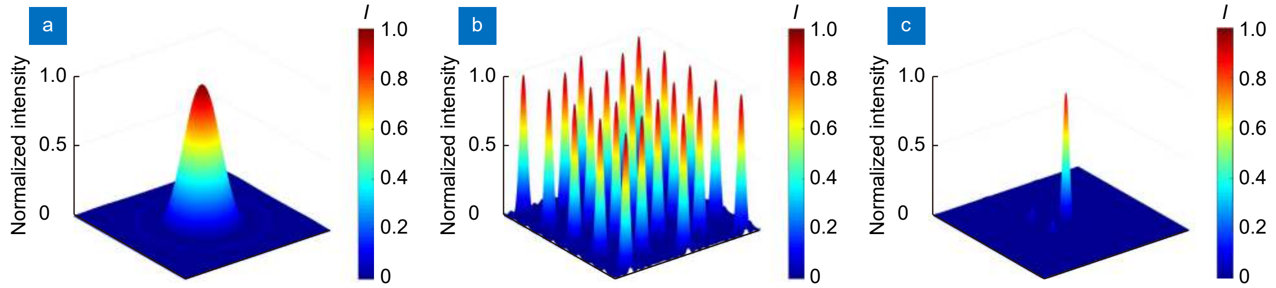

图 4　光纤激光相控阵扫描模型的远场分布示意图。
(a) 包络因子；(b) 网格因子；(c) 远场强度分布
Fig. 4　Far-field distribution diagram of fiber laser phased array steering model.
(a) Envelope factor; (b) Grid factor; (c) Far-field distribution

当光束偏转角度$\theta$较小时，$\theta$与相邻子孔径所施加相位差$\Delta\varphi$之间的关系为[1]

$$\theta = \arcsin\left(\Delta\varphi\cdot\frac{\lambda}{2\pi s}\right), \tag{6}$$

式中：$s$为相邻子孔径间距，本文的相控阵模型沿$x$轴和$y$轴的相邻子孔径间距为$s_x$与$s_y$。根据式 (6) 描绘出光束偏转的$s$-$\theta$双对数坐标图，如图 5 所示。其中，固定入射光波长$\lambda$，起始横坐标的子孔径间距$s$为微米量级，对应液晶相控阵、硅基相控阵等子孔径间距的主要尺度范围。由图 5 可见，偏转角度$\theta$随孔径间距$s$减小而单调递增，且在偏转角度$\theta$数值较小时可近似为线性关系；子孔径间距$s$一定时，随着施加相位差$\Delta\varphi$的递增偏转角度$\theta$逐渐增加。目前光纤激光相控阵子孔径间距的尺度范围通常为几十毫米，对应的光束偏转角度$\theta$为 μrad 量级，可应用于超远距离目标的高精度激光探测。

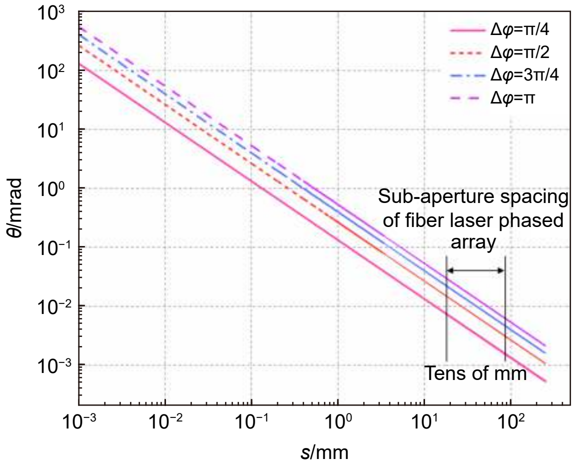

图 5　双对数坐标下 $s$-$\theta$-$\Delta\varphi$ 的关系图
Fig. 5　The relationship diagram of $s$-$\theta$-$\Delta\varphi$ in double logarithmic coordinates

## 3　多孔径光纤激光相控扫描结果

建立了等效口径为米量级的 19、133、703 孔径光纤激光相控阵模型，并对光束扫描效果进行分析。图 6 为正六边形排布的三种光纤激光相控阵模型的近场分布，虚线表示模型的等效口径$D$，参数设为 1.1 m。详细参数如表 1 所示。

### 3.1　多孔径光纤激光相控扫描远场光束形态

对上述 3 种多孔径光纤激光相控阵方案的光束扫描效果进行分析。改变相控阵相邻子孔径间的活塞相位差$\Delta\varphi$，在远场实现了沿$x$和$y$轴的光束偏转，根据光波的周期性将活塞相位差$\Delta\varphi$的调节范围等效为$[-\pi, \pi]$。图 7~图 9 分别为 19、133、703 孔径相控阵在沿$x$轴扫描时，部分远场扫描光斑的归一化光强分布。外圈虚线表示为非相干“桶”的范围$D_{\mathrm{N}} = \dfrac{2.44\lambda}{d}$，当$\Delta\varphi = 0$时所有的干涉峰都位于其衍射限制的“桶”直径内，同时外圈虚线表示主瓣的最大扫描范围。内圈虚线表示为相干“桶”的范围$D_{\mathrm{C}} = \dfrac{2.44\lambda}{D}$，当$\Delta\varphi = 0$时中心主瓣位于其衍射限制的“桶”直径内。根据瑞利判据，扫描精度取决于输出光束的远场主瓣大小，其中等效口径$D$与远场主瓣大小成反比，因此等效口径可决定扫描的精度。

当$\Delta\varphi = 0$时，光束平行出射，远场光斑图样中心位置处有一个明显的高亮度主瓣，主瓣四周伴有规律分布的弱栅瓣，且光束的强度分布沿$x$和$y$轴对称，如图 7~图 9 的 (e) 所示。在光束扫描过程中，当活塞相位差$\Delta\varphi$从 0 到$\pi$等间距变化时，包络因子保持不变，网格因子受到相位调制其位置发生变化，使主瓣由中心位置沿$x$轴右侧横向移动，扫描角度逐渐增大，此时光束的强度分布仅沿$x$轴对称；由于受到包络因子和网格因子的调制，随着扫描角度增大，主瓣能量

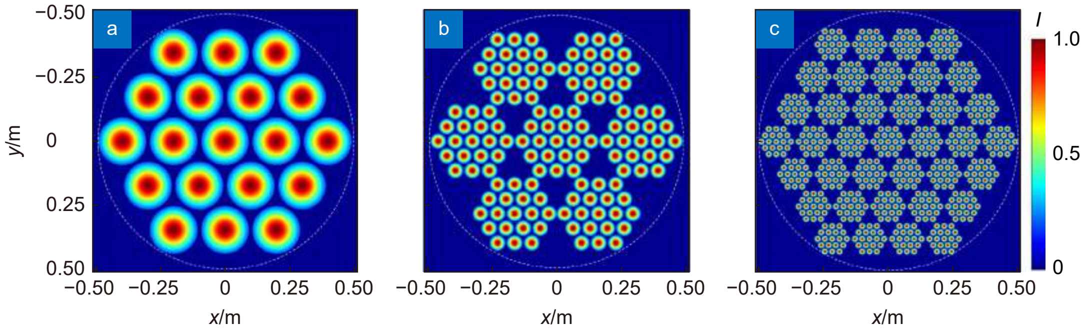

图 6 光纤激光相控阵模型的近场分布示意图。(a) 19 孔径；(b) 133 孔径；(c) 703 孔径

Fig. 6 Near-field distribution diagram of fiber laser phased array model. (a) 19 apertures; (b) 133 apertures; (c) 703 apertures

表 1 光纤激光相控阵模型参数

Table 1 Parameters of fiber laser phased array models

| Array sizes | $\lambda$/nm | $\omega_0$/mm | $D$/m | $d$/mm | $s_x$/mm | $s_y$/mm |
|---|---|---|---|---|---|---|
| 19 apertures | 1064 | 79 | 1.1 | 202 | 112 | 194 |
| 133 apertures | 1064 | 26 | 1.1 | 66 | 36.5 | 63 |
| 703 apertures | 1064 | 11 | 1.1 | 28 | 15.5 | 26.8 |

占比逐渐下降，大部分能量泄漏到位于主瓣左侧的两个栅瓣中。在图 7~图 9 的 (h)、(i) 中，可以观察到，栅瓣的峰值强度明显大于主瓣。此时，扫描光束在远场靶面上的能量集中度较差，容易影响远场主瓣的位置计算，从而干扰扫描光束的精确指向控制。因此，将主瓣与栅瓣光强峰值比等于 1 时，定义为扫描的极限范围。相位差$\Delta\varphi$从 0 到$-\pi$ 等间距变化过程与 0 到 $\pi$ 变化过程关于 $y$ 轴对称。

当光纤激光相控阵沿 $y$ 轴扫描时，远场光斑形态与沿 $x$ 轴方向扫描存在差异，这是由于光纤激光相控阵模型在正交轴上的不对称所造成的。图 10~图 12 分别为 19、133、703 孔径相控阵沿 $y$ 轴扫描时，部分远场扫描光斑的归一化强度分布。随着活塞相位差$\Delta\varphi$从 0 到 $\pi$ 等间距变化，主瓣由中心位置沿 $y$ 轴下侧纵向移动，扫描角度增大，伴随角度的增大主瓣能量逐渐泄漏到位于主瓣上侧的一个栅瓣中。同样，相位差$\Delta\varphi$从 0 到$-\pi$ 等间距变化过程与 0 到 $\pi$ 变化过程关于 $x$ 轴对称。

### 3.2 多孔径光纤激光相控扫描过程

19、133、703 孔径沿 $x$ 轴的近衍射极限连续扫描过程如图 13~图 15 所示，虚线表示相位差$\Delta\varphi = 0$时的远场扫描光斑剖面图，空心圆曲线为扫描极限光斑，实线为连续扫描过程中包含的扫描光斑。扫描结果显示，当主瓣与栅瓣的峰值强度比为 1 时，对应的相邻子孔径间相位差为$\Delta\varphi = \pm 0.666\,\pi$，此时远场光斑图中出现了两个与主瓣光强能量值相同的栅瓣，如图 13~15 的 (b)、(c) 所示。当$\Delta\varphi = \pm 0.666\,\pi$时，19、133、703 孔径相控阵沿 $x$ 轴的扫描极限范围分别为±3.1 μrad、±9.3 μrad、±21.9 μrad。由于等效口径相等，则扫描精度一致，随着子孔径数目增加，子孔径间距减小，扫描范围增大，在扫描范围内可覆盖的近衍射极限光斑也就越多。

图 16~图 18 分别为 19、133、703 孔径沿 $y$ 轴的近衍射极限连续扫描过程。虚线表示相位差$\Delta\varphi = 0$时远场扫描光斑剖面图，空心圆曲线为扫描极限光斑，实线为连续扫描过程中包含的扫描光斑，图中空心圆曲线外侧部分的光斑为造成干扰的栅瓣。由于光纤激光相控阵模型在正交轴上子孔径的位置排布和间距大小的不一致，造成了 $x$ 和 $y$ 方向的扫描范围不一致。在沿 $y$ 轴的扫描过程中，同样定义当主瓣与栅瓣的峰值强度比为 1 时为扫描极限范围，此时对应的相位差$\Delta\varphi = \pm\pi$，远场光斑图中出现一个与主瓣光强能量值相同的栅瓣，如图 16~18 的 (b)、(c) 所示。当$\Delta\varphi = \pm\pi$时，19、133、703 孔径相控阵沿 $y$ 轴的扫描极限范围分别为±2.4 μrad、±8.1 μrad、±18.9 μrad。

多孔径光纤激光相控阵模型的扫描精度及扫描极限范围由表 2 所示。根据前面的分析，可知等效口径影响分辨率，等效口径越大分辨率越高，因此要提升系统的分辨率可增大相控阵系统的等效口径尺寸。对于文中所提到的 1.1 m 量级相控阵模型的分辨率为 1.2 μrad。当等效口径相同时，远场主瓣大小一致，

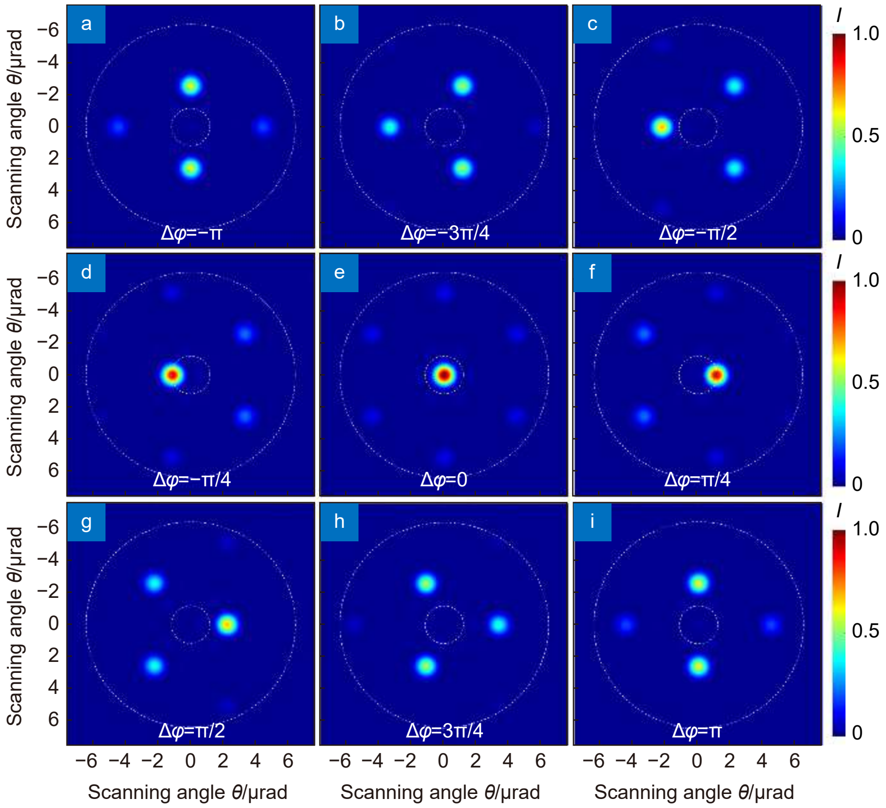

图 7 19 孔径沿 *x* 轴扫描过程中的部分远场光斑分布图

Fig. 7 Partial far-field spot distribution of 19 apertures in *x*-axis scanning process

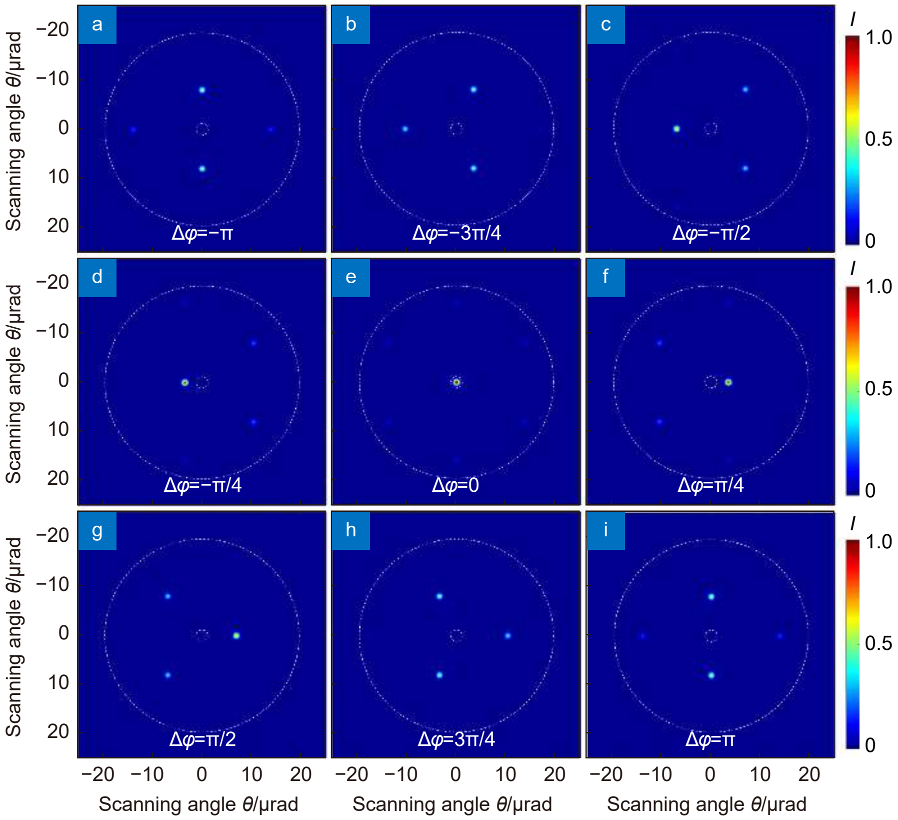

图 8 133 孔径沿 *x* 轴扫描过程中的部分远场光斑分布图

Fig. 8 Partial far-field spot distribution of 133 apertures in *x*-axis scanning process

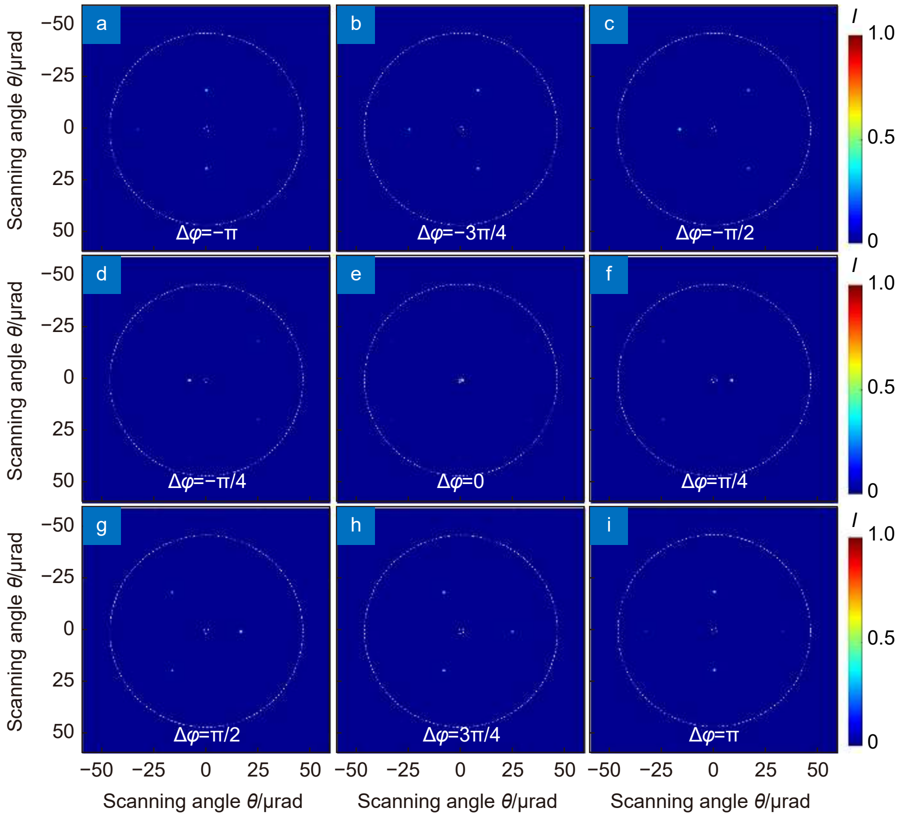

图 9　703 孔径沿 *x* 轴扫描过程中的部分远场光斑分布图

Fig. 9　Partial far-field spot distribution of 703 apertures in *x*-axis scanning process

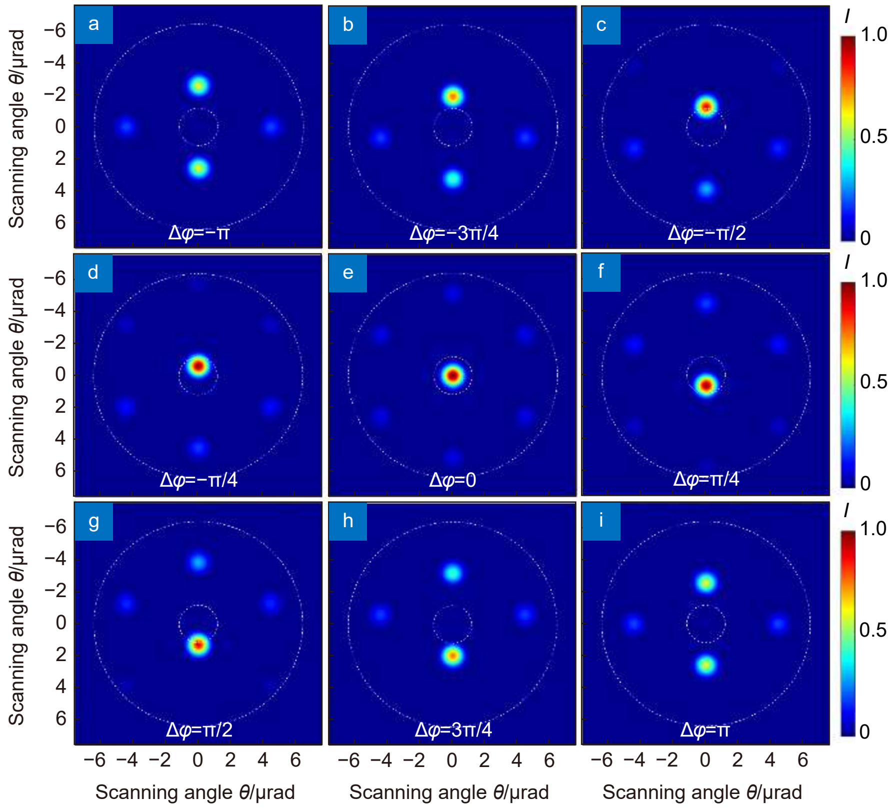

图 10　19 孔径沿 *y* 轴扫描过程中的部分远场光斑分布图

Fig. 10　Partial far-field spot distribution of 19 apertures in *y*-axis scanning process

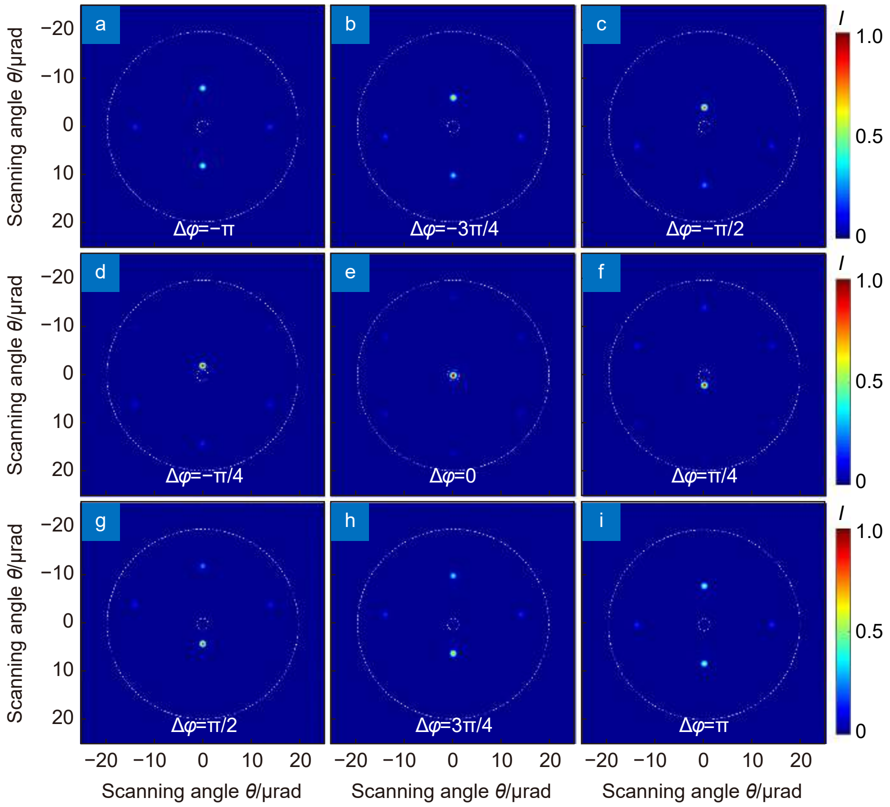

图 11　133 孔径沿 *y* 轴扫描过程中的部分远场光斑分布图

Fig. 11　Partial far-field spot distribution of 133 apertures in *y*-axis scanning process

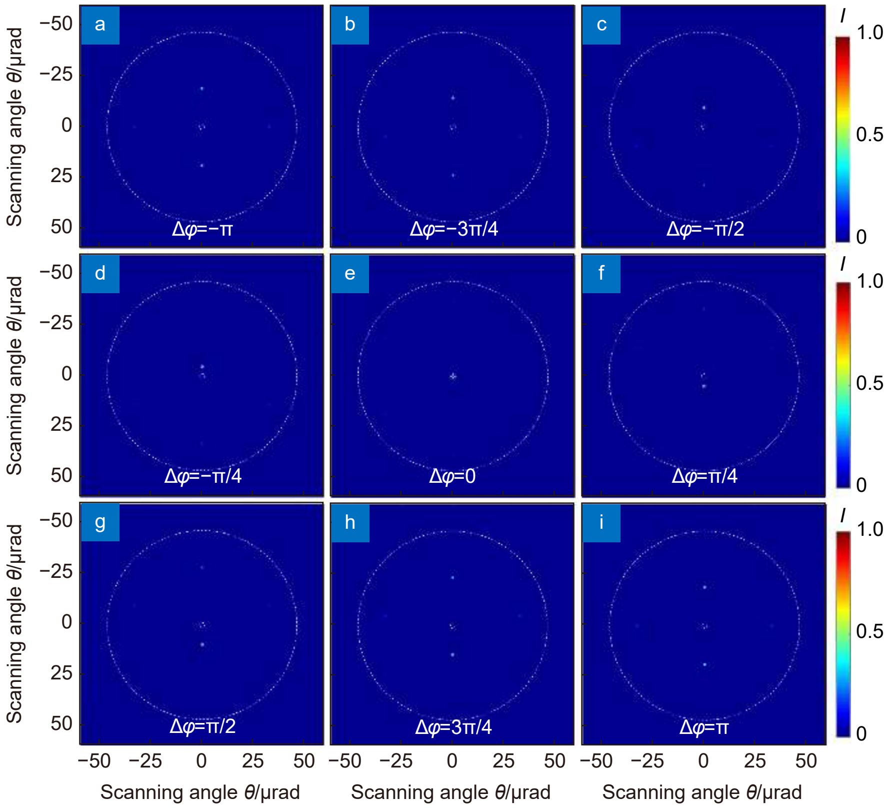

图 12　703 孔径沿 *y* 轴扫描过程中的部分远场光斑分布图

Fig. 12　Partial far-field spot distribution of 703 apertures in *y*-axis scanning process

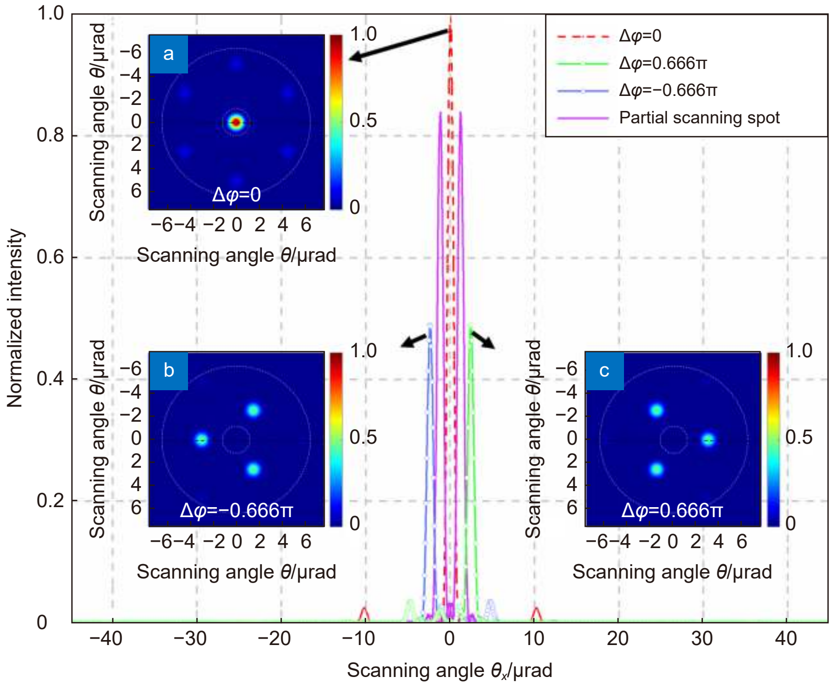

图 13 19 孔径沿 *x* 轴的近衍射极限连续扫描过程图

Fig. 13 Near diffraction limit continuous scanning process of 19 apertures along *x*-axis

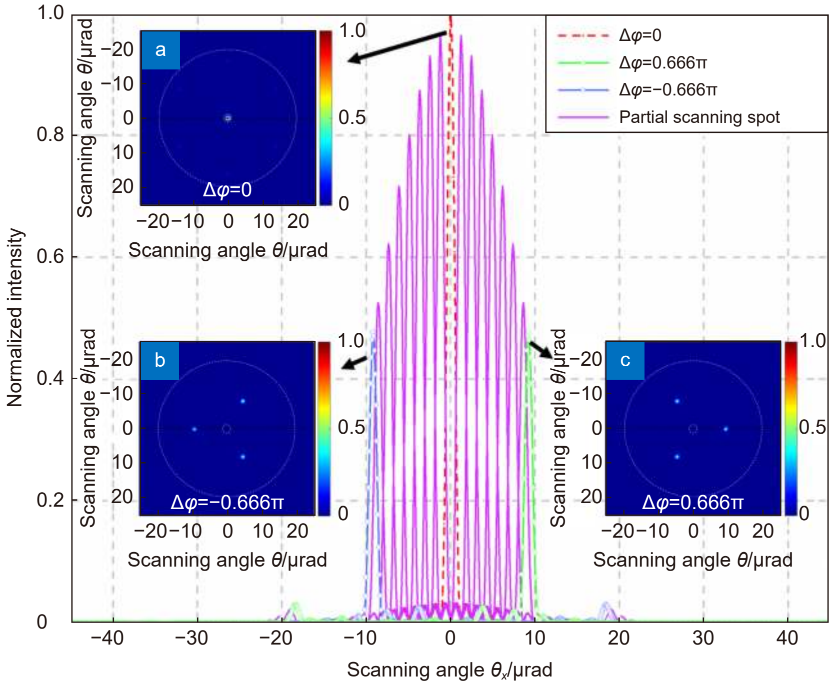

图 14 133 孔径沿 *x* 轴的近衍射极限连续扫描过程图

Fig. 14 Near diffraction limit continuous scanning process of 133 apertures along *x*-axis

则扫描精度一致。随着子孔径数目的增加，子孔径间距减小，扫描范围增加。由表 2 得出，相较于 19 和 133 孔径相控阵模型，703 孔径相控阵模型能将沿 *x* 轴与 *y* 轴的光束扫描范围分别提升约 7 倍和 2 倍。因此可根据实际应用场景设计相控阵扫描系统参数，合理选择口径尺寸和孔径数目。图 19 为多孔径光纤激光相控阵在一个周期内分别沿 *x* 和 *y* 轴高精度扫描的轨迹图，扫描最亮点为主瓣，其周围为栅瓣。从结果对比得出，在同样的等效口径下，可适当选择较小的子孔径间距，获得更大的扫描视场角。

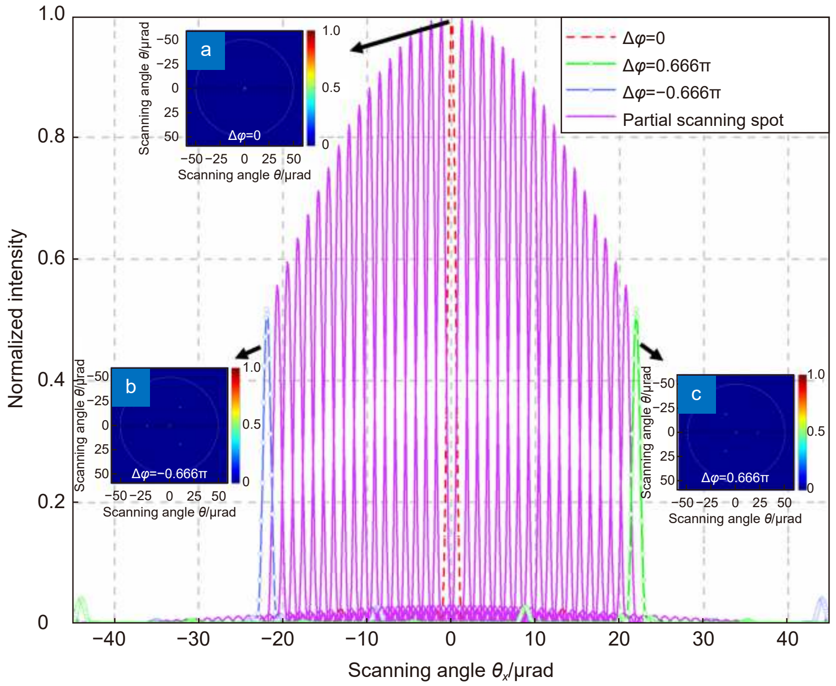

图 15　703 孔径沿 *x* 轴的近衍射极限连续扫描过程图

Fig. 15　Near diffraction limit continuous scanning process of 703 apertures along *x*-axis

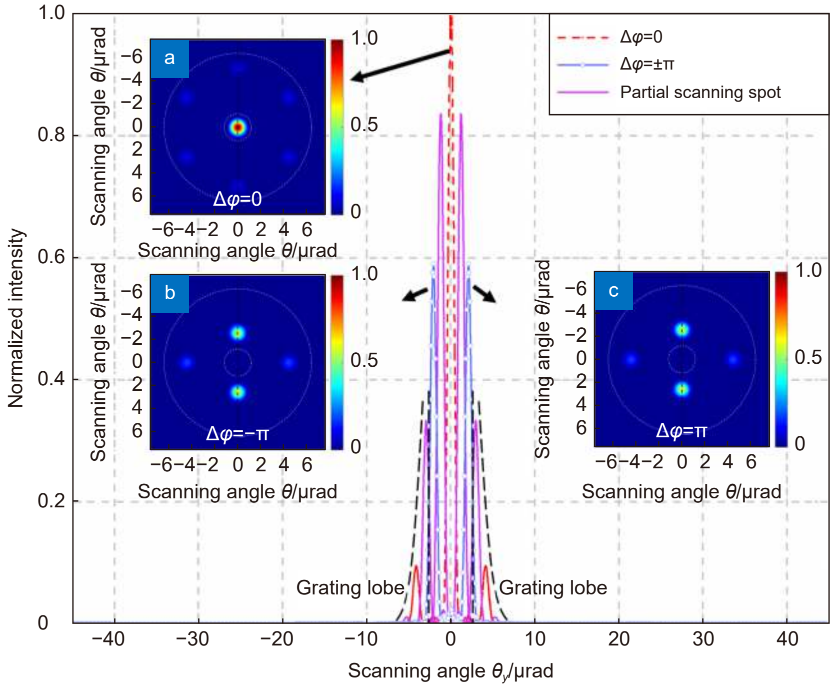

图 16　19 孔径沿 *y* 轴的近衍射极限连续扫描过程图

Fig. 16　Near diffraction limit continuous scanning process of 19 apertures along *y*-axis

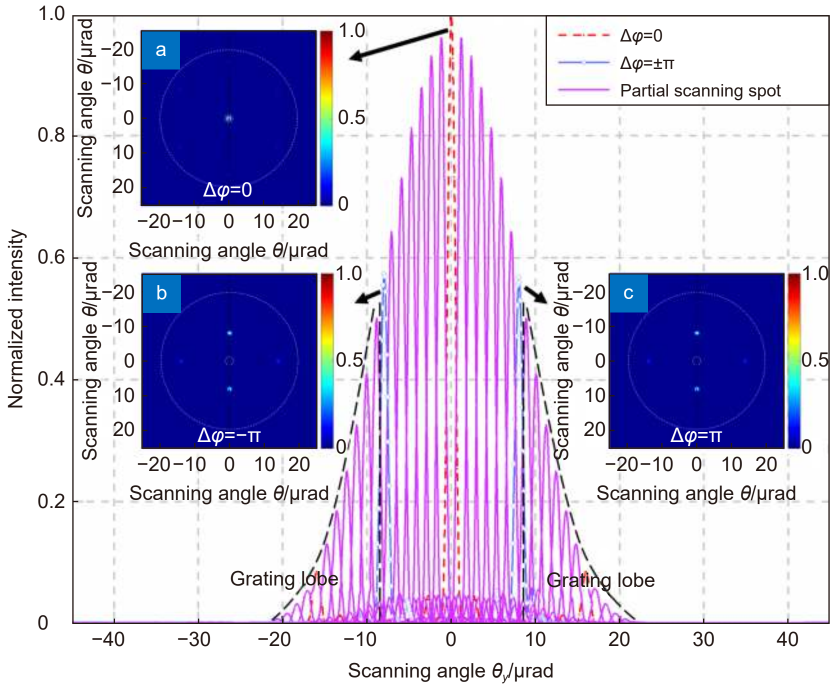

图 17 133 孔径沿 *y* 轴的近衍射极限连续扫描过程图

Fig. 17 Near diffraction limit continuous scanning process of 133 apertures along *y*-axis

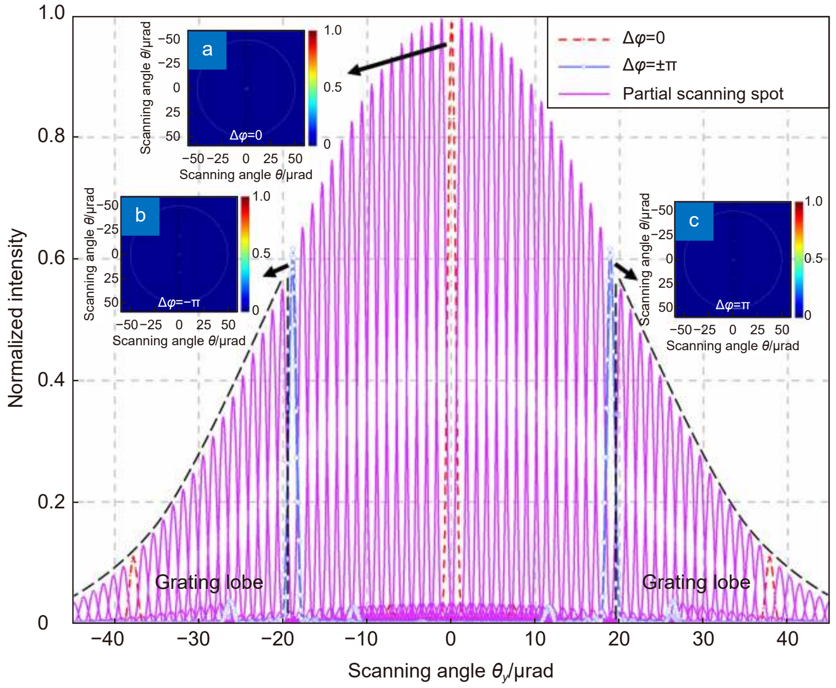

图 18 703 孔径沿 *y* 轴的近衍射极限连续扫描过程图

Fig. 18 Near diffraction limit continuous scanning process of 703 apertures along *y*-axis

表 2 多孔径光纤激光相控扫描结果

Table 2 Simulation results of multi-aperture fiber laser phase controlled scanning

| Array sizes | $\delta_\theta$/μrad | $\theta_x$/μrad | $\theta_y$/μrad |
|---|---|---|---|
| 19 apertures | 1.2 | ±2.96 | ±2.43 |
| 133 apertures | 1.2 | ±9.27 | ±7.96 |
| 703 apertures | 1.2 | ±21.88 | ±18.91 |

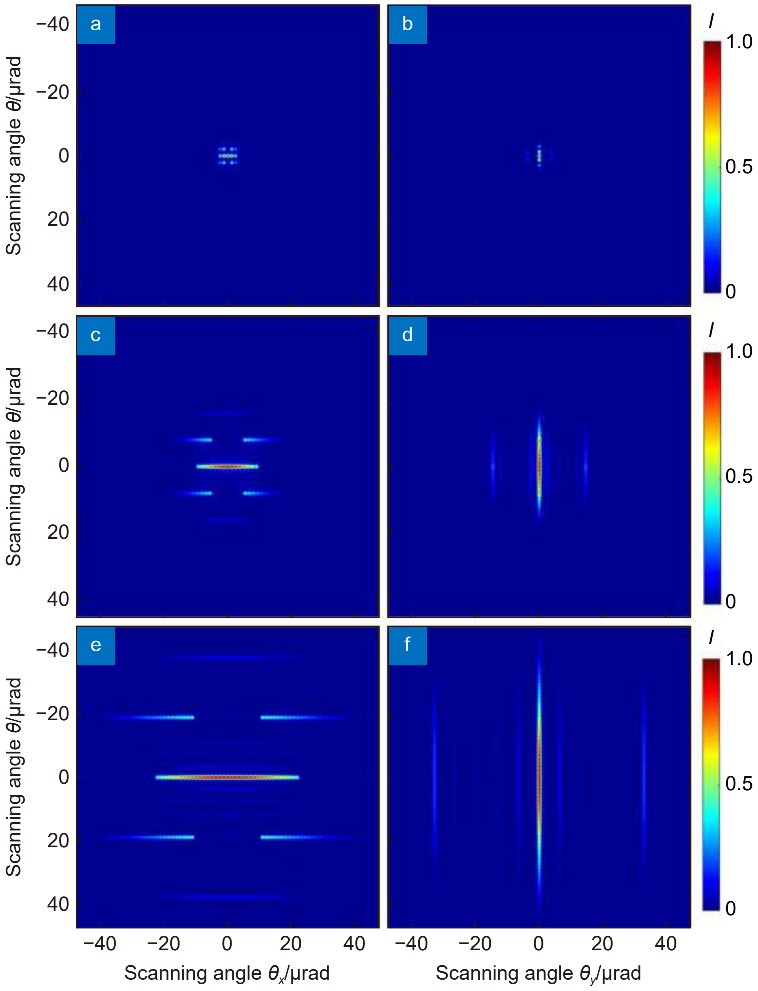

图 19 多孔径光纤激光相控阵在一个周期内的扫描轨迹图。

(a)、(c)、(e) 分别为 19、133、703 孔径沿 *x* 轴扫描；(b)、(d)、(f) 分别为 19、133、703 孔径沿 *y* 轴扫描

Fig. 19 Scanning trajectories of multi-aperture fiber laser phased array in one period.

(a), (c) and (e) are 19, 133 and 703 apertures scanning along *x*-axis respectively; (b), (d) and (f) are 19, 133 and 703 apertures scanning along *y*-axis respectively

## 4 结 论

本文以 19 孔径光纤激光相控阵为基础模块，针对甚多孔径光纤激光相控阵技术的发展趋势，建立了 19、133、703 孔径的米量级相控阵发射系统模型。通过改变米量级相控阵系统相邻子孔径间的相位差，可实现在一定范围内的光束高精度二维扫描。根据扫描光束形态的分布特点，定义并计算了 19、133、703 孔径光纤激光相控阵的扫描极限范围。研究结果表明，不同的阶梯相位分布模式对应不同的远场扫描光束能量分布，随着相位差的增大，主瓣峰值强度随之变化，其能量泄漏到栅瓣中。当沿 $x$ 和 $y$ 轴扫描的子孔径间相位差分别限制在[$-0.666\pi$，$0.666\pi$]、[$-\pi$，$\pi$]范围内时，主瓣与栅瓣的峰值强度比大于 1，由此确定光束的扫描极限范围。通过对多孔径、米量级光纤激光相控阵扫描特性的研究，有望实现对远距离目

标的精确跟瞄和一定范围的光束快速覆盖，拓展并丰富了光纤激光相控阵波前相位操控的能力边界和应用范围。

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# Research on beam steering of numerous sub-aperture fiber laser phased array

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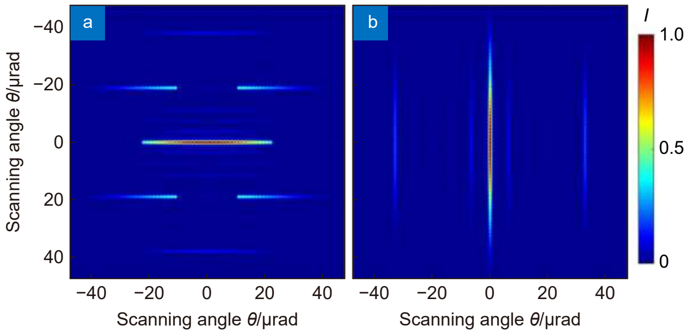

Steering trajectories of a 703 aperture fiber laser phased array along the *x* and *y* axes in one period

**Overview:** Numerous sub-aperture fiber laser array is one of the emerging technologies to build high power, high beam quality and equivalent optical large aperture. Realizing the common phase and even the fast and flexible beam deflection of array laser beam based on the precise phase control is the key to the application of the current fiber laser phased array technology. In this paper, the optical phase-controlled steering technology is combined with the fiber laser coherent combining system, and the beam steering characteristics of the numerous sub-aperture, meter-scale fiber array laser coherent combining system are studied. Aiming at the development trend of numerous sub-aperture fiber laser phased array technology, based on the 19 aperture fiber laser phased array as the basic module, the meter-scale phased array transmitting system models with 19, 133 and 703 apertures are established. Based on the principle of optical phased array, the step phase folding model is adopted to make the piston phase distribution of the beam emitted from adjacent aperture change continuously, and to realize the high-precision continuous steering in a certain range. Meanwhile, the steering limit ranges of 19, 133 and 703 aperture fiber laser phased arrays are defined and calculated according to the distribution characteristics of the far-field steering beam pattern. Through numerical simulation analysis, the results show that when the piston phase difference of adjacent sub-apertures changes at equal intervals, the far-field main lobe position changes, and the steering angle gradually increases with the increase of phase difference. When the steering angle increases, the far-field main lobe energy gradually leaks into the grating lobes, which reduces the peak light intensity of the main lobe. When the peak intensity of the grating lobe is stronger than the main flap, the energy concentration of the steering beam on the far-field target surface is poor, which easily affects the position calculation of the far-field main lobe and interferes with the precise pointing control of the steering beam. Therefore, the limit range of steering is defined when the peak intensity ratio of the main lobe to the grating lobe is equal to 1. When the fiber laser phased array steers along the *x*- and *y*-axes respectively, there are obvious differences in the far-field spot shape and steering range, which is caused by the asymmetric structure of the fiber laser phased model. In this paper, the phased array models with apertures 19, 133 and 703 have equivalent diameters. As the number of sub-aperture increases, the aperture spacing decreases and the steering range increases. Therefore, the parameters of the phased array steering system can be designed according to the actual application scenario, and the aperture size and aperture number can be selected reasonably. By studying the steering characteristics of numerous sub-aperture and meter aperture fiber laser phased arrays, this paper enriches the beam wavefront control ability of fiber laser phased array technology, which can be used for precise tracking of ultra-long-distance targets and fast beam coverage in a certain range.

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